# The quality of milk powder and its dependency on equipment maintenance Management.

**By**

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*Submitted in partial fulfilment of the requirements for a Masters of Business Administration degree at Massey University. New Zealand.*

*March 2013*

## Abstract

By 2012 the dairy industry in New Zealand had grown by 77% since 1992 and is estimated to reach total export values of over 17 billion dollars by 2016. Like most food industries around the World, quality failures in the industry pose a serious threat in the production of milk powder. The melamine contamination experience at San Lu in China in 2008 is a case in point. Such experiences could results in costly product recalls and damaged brands among other undesirable consequences.

A local dairy factory that manufactured 130 698 metric tons of powder milk in 2012, lost 3.4% of its production due to various quality issues. The 3.4% production loss translated to 7.5 million dollars in lost revenue and is clear evidence that there is room for improvement in the mitigation of cost of quality failures.

The purpose of this study is to identify quality failure causes and their relationship to equipment maintenance management. The identification of this relationship may then lead to rethinking of how maintenance management techniques could be improved with a focus on mitigating quality failures. The quantitative research design examines maintenance and production data collected from the factory covering a 12 month period and attempts to establish a correlation between these two data streams. It also examines the input of maintenance staff through a survey, to determine their awareness to their contribution or lake of to improving product quality.

The results show a clear relationship between product downgrade and maintenance related unplanned stoppages. They also indicate that there is a high awareness within the maintenance team that their actions contribute to product quality, but there is less engagement to executing maintenance activities with a focus on product quality. Further research on a wider over a longer time period is recommended in order to derive quality focused maintenance strategies that can effectively drive down the cost of quality failures.

## Acknowledgements

I would like to start by thank my research supervisor Dr Nigel Grigg for his guidance and support during the course of this research. I am also grateful for the contribution and expertise of my co-workers in the maintenance department in general and the reliability engineering team in particular. I gratefully acknowledge the contribution in time, data and expertise from the Powder Plant staff, their management team and the company's senior management for allowing my research to go ahead. I would also like to thank the staff of the Massey MBA program for their assistance which resulted in the successful completion of this study.

Finally my thanks goes to my family for their patience and support during the long hours spent in the study and on study tours away from them.

## Statement of Academic Integrity

I declare that this research project is entirely my own work and has not been taken from the work of others. When the ideas, quotations, data and diagrams of others have been used in the study, the work has been properly cited in the text.

*Signature: Ambrose T Mpofu .*

*Date: 01 March 2013 .*

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| | |
|---|---|
| F12 | August 2011 – July 2012 Production Season |
| TQM | Total Quality Management. |
| COQF | Cost of quality failures. |
| RM | Reactive maintenance. |
| PM | Preventive maintenance. |
| RCM | Reliability centred maintenance. |
| ISO | International Organization for Standardization |
| JIT | Just in time. |
| TPM | Total productive maintenance. |
| TQC | Total quality control. |
| FA | Factory automation. |
| TPS | Toyota Production System |
| OE | Operational excellence. |
| SS | Six Sigma. |
| GE | General Electric. |
| DFSS | Designed for six sigma |
| PdM | Predictive Maintenance |
| FMEA | Failure mode effect analysis |
| FMECA | Failure mode effect critical analysis. |
| RCA | Root cause analysis. |
| PHA | Physical hazard analysis. |
| FTA | Fault tree analysis. |
| OMF | Optimisation Maintenance function |
| HAZOP | Hazard and operability |
| CBM | Condition based maintenance. |
| MTBF | Mean time between failures |
| MTTF | Mean time to fail |
| MTTR | Mean time to repair |
| PAF | Preventive, Appraisal and Failure |
| ASQ | American Society for quality |
| BSi | British Standards Institute |
| CMMS | Computer maintenance management system |
| SPSS | Statistical Package for the Social Sciences |
| PQDR | Product quality deficiency reports |
| LRN | Low risk notification. |
| CM | Corrective maintenance |

# CHAPTER ONE: INTRODUCTION

## 1.1 INTRODUCTION

A local milk production site lost over 15 million dollars during the 2011 to 2012 season (F12) due to cheese and milk powder products not meeting the site's own minimum levels of quality. This resulted in product downgrades and product being put on hold while investigations are done. Some of the losses were due to product not getting to their customer in an acceptable minimum standard resulting in customer complaints. The site management team has decided to focus more attention in improving product quality in the next milk cycle, with a goal to save at least 60% of the last season's losses. They have made achieving a quality product the responsibility of everyone through the supply chain.

Programs such as Total Quality Management (TQM), Lean Manufacturing and Six Sigma are designed to help companies improve the quality of their products (Deming 1982). These companies spend a sizeable amount of their operating expenses on making sure the product they manufacture meets or exceeds their customer's expectations and that their production systems are doing the right things right, right away. These costs represent a considerable portion of the company's cost of sales (Giakatis, Enkawa et al. 2001). Large amounts of most maintenance budgets are also spent on equipment and maintenance management improvement activities that include maximizing equipment effectiveness and eliminating the six big equipment-related losses. These losses come from downtime losses due to breakdowns, setup and adjustments of equipment. They also come from slow production speed due to small stoppages and reduced equipment speed. Quality losses come from start-up, and production rejects (Hemant 2010). Although not always 100 percent achievable at all times, perfect product quality and 100% machine availability or the duration of time the machine is capable of being used, are some of the most important key performance indicators of most manufacturing processes. Companies aim to produce more high-quality products at the lowest cost. Equipment is usually maintained in order to produce a product within an acceptable cost and time period (Koenig 1994).

This report will present research into the relationship between how manufacturing assets are managed and maintained and the quality of the products they make in the New Zealand dairy industry in general. This will be done by studying the quality failure related issues in the production of powder milk at a local powder plant, which will be referred to as Plant A to maintain its anonymity. The research will look into the whether the cost associated with low quality products, that is, product downgrade, product holdups and customer complaints can be reduced by changing asset maintenance strategies. The data that will be used in this research will mainly be from the New Zealand dairy industry in general as secondary data and from Plant A as primary data. Any findings from this research are aimed at contributing to the body of knowledge that can be used in reducing the costs associated with low product quality in any milk powder manufacturing environment and help maintenance departments understand the equipment focus areas that may contribute to the improvement of product quality.

## 1.2 PURPOSE OF THE STUDY

Every possible means of improving product quality should be identified, empirically tested and exploited by any manufacturer who wants to stay competitive. The amount of money lost through the cost of quality failure in most production systems is evidence that there is room for improvement. The purpose of this study is to contribute to the knowledge of identifying quality failure causes that are related to the equipment used during the manufacturing process of milk powder. A better understanding of the relationship between product quality and the maintenance of the equipment, may lead to the re-examining and improvement of maintenance management techniques. Subsequently, this may lead to the improvement of the quality of milk powder and the reduction of cost of quality failures. The knowledge may then be transferred to other manufacturing environments outside the dairy industry if compatible.

### 1.2.1 Problem Statement

Product quality is a critical part of any food manufacturer. It is very important to the dairy industry in general and Plant A, in particular. During the 2011-2012 (F12) season, milk powder production quality issues cost the factory $7.5 million. Each step of powder milk production, from collection to customer, involves the use of regularly maintained equipment. Imperfections in the equipment or its maintenance contribute to the cost of quality failures (COQF).

In this research, product quality whose failure results in COQF means the minimum acceptable characteristics that meet the plant's and/or the customer's standard. Failure to meet the standard results in product downgrades or product on hold or customer complaints. Therefore, the less the downgrades, complaints and product on hold the better the quality.

### 1.2.2 Research Questions

The main research questions based on the problem statement are:

1. What are the quality attributes of powder milk that depend on effective equipment maintenance?
2. Can powder milk quality issues be mitigated by changes in equipment maintenance strategies and implementation?
3. To what extent are maintenance strategies and personnel involved in continuously improving the quality of milk powder?

### 1.2.3 Research Significance

The loss of $7.5 million in one production season at Plant A is evidence that there is room for improvement in lowering quality failures. Any contribution that can help improve product quality and reduce maintenance cost will be significantly important to Plant A, in particular, and the dairy industry in general. Product quality is far more critical in any food industry than in most industries. The melamine baby formula contamination incident in China in 2008 that resulted in the death and grave illness of a large number of babies is one example of the serious repercussions of poor product quality (Exporter 2009). The incident cost Fonterra over 200 million dollars of investments, resulted in San Lu being declared bankrupt and some of its senior managers being jailed. Other repercussions of poor-quality products include large-scale product recalls costing companies significant amounts of money, reputation and customers, like the recalling of Toyota cars in 2010 (Piotrowski and Guyette 2010).

Exploring the relationship between maintenance and quality will contribute to the body of knowledge that aims to find ways of improving the performance of production equipment that is directly linked to the increase in product quality and low cost. The effectiveness of production philosophies like Lean manufacturing or Six Sigma depends on effective maintenance programs. Regular planned preventive maintenance, in the long term, costs are far less than the cost of breakdowns. Breakdown costs during a production cycle include production stoppages, labour costs, damaged or downgraded products and repair costs among others.

Improved product quality will improve business' competitive advantage and profitability (James and William 2008). High product quality, low quality costs can be achieved by eliminating defects, performing regular quality inspections and avoiding reworks as well as eliminating warehousing costs due to product on hold.

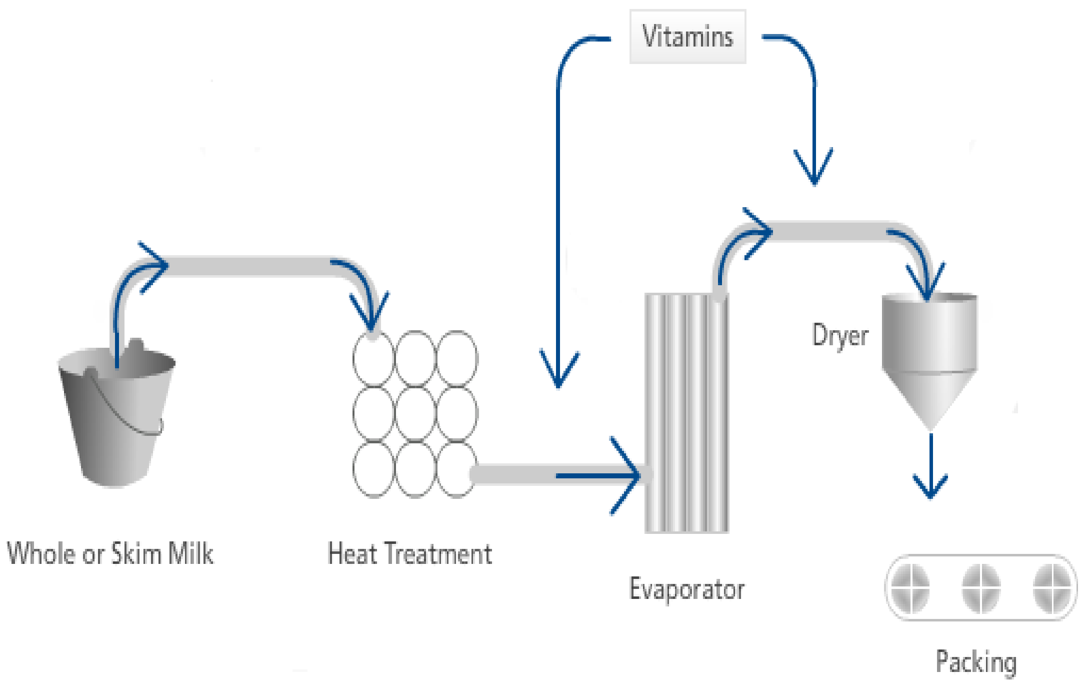
## 1.3 Background to the Study

There are two important factors of the production process that have a direct impact on the quality of milk powder, that is, the human factor and the machine factor. The improvements in machine technology over the years have increased the machine factor and decreased the human factor. Humans are known to increase process variability by being less reliable and less consistent compared to machines (Bullinger, Warnecke et al. 1986). Highly mechanised manufacturing systems have increased efficiency and consistency, but require highly skilled maintenance capabilities and sophisticated and specialised spare parts. This could mean high maintenance cost resulting in increased production costs. Highly skilled production staff and efficient and reliable machines produce high-quality products at minimum costs. On the contrary, human error and ineffective equipment can result in low quality products and high production costs.

It has become the goal of many manufacturing processes, that where speed, design accuracy and strict tolerances are required, machines are preferred. For instance, machines are increasingly used in identification systems like barcode scanners and access control. They are also used in automated storage and inventory controls, robotic packers, and other advanced manufacturing processes. The production of milk powder has not been spared the automation advancement.

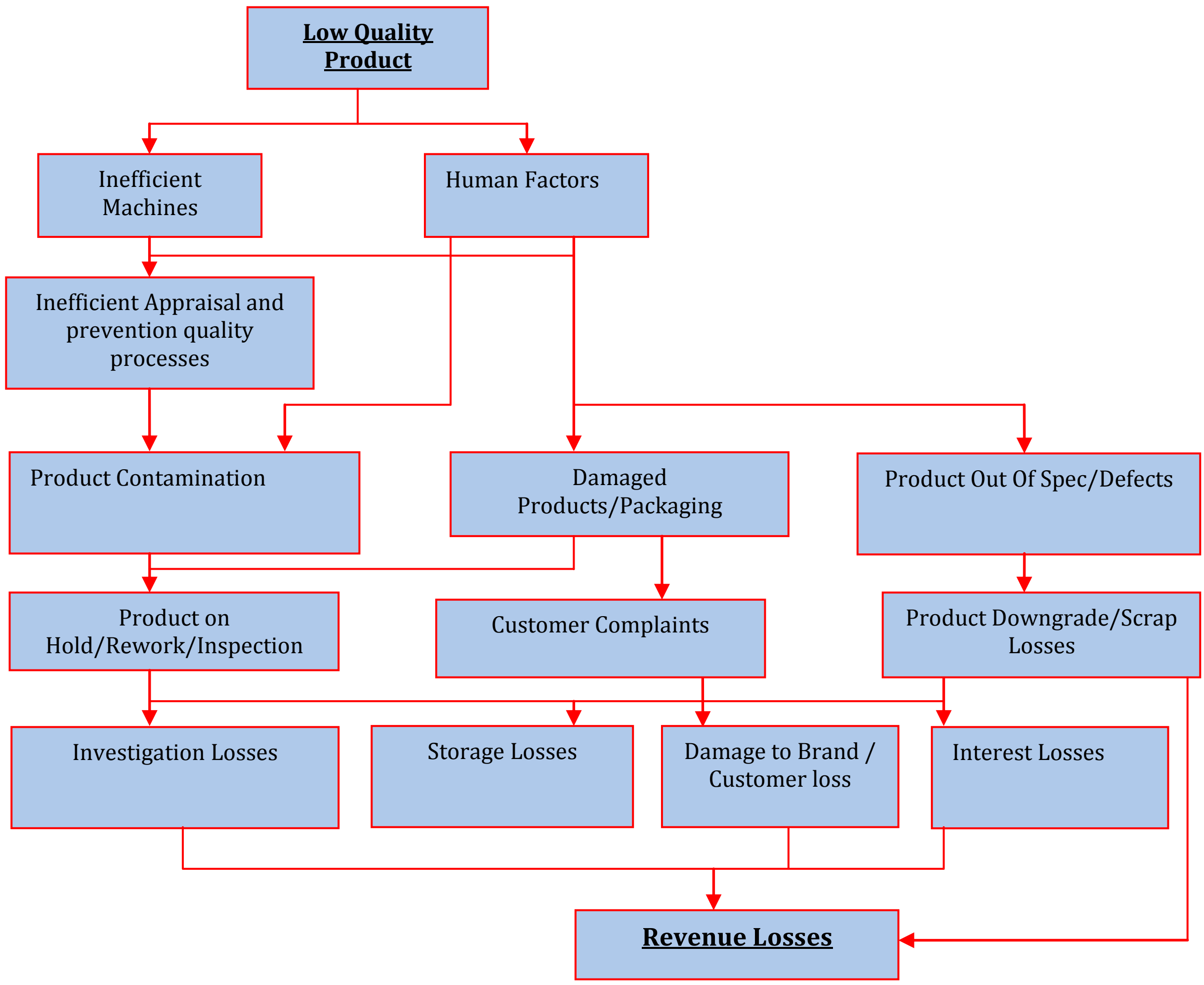
The process of powder milk production at Plant A starts with the raw milk collected from the farms being split into cream and skim milk in a process called separation that uses mechanical separation by centrifugal force. The separated components are then pasteurized by heating at 72 Celsius for 20 seconds to kill bacteria and stabilize the fats, Figure1. Depending on the product being made, they are subsequently recombined in different quantities. For example, in the making of whole milk powder, some of the cream is recombines with skim milk. This is followed by evaporation, where the milk is boiled at high temperatures in a vacuum until it has lost 50 per cent of its water content. The next process is drying using a spray dryer. This process removes the extra water by blowing very hot air at 200 degrees Celsius into tubes that contain the water milky mixture. The hot air evaporates the water lowering the moisture content from 50 to about 6 per cent. The ideal moisture content is about 2 per cent. To achieve this; the powder is shaken through fluid beds, while blowing hot air as it rolls from one end of the bed to the outlet. During this process, lecithin is added to the milk powder to improve the wettability and dispersibility of the powder when it is mixed with water. After cooling down, the powder is packed into bags ready for transporting to the customer. All these processes are highly automated with little or no human input.

**Figure 1. The Making of Whole Milk Powder**




The Plant A employees about 40 people and is managed by a plant manager assisted by a process manager. Employees are divided into four shifts that run the plant 24/7 and each shift is managed by a supervisor. The plant produced a record 130 697 metric tonne of milk powder during the 2011 to 2012, season. The cost of quality failure for this record tonnage was just over $7.5 million due to downgrades, complaints and product on hold. The five leading downgrade issues recorded were sieve test, bulk density, wettability, miscibility and low protein limit. The five topmost complaint issues were scorched particles, foreign matter, chemical, functional and shipping issues. The major product on hold issue was suspected foreign matter in the product. Out of the top five downgrade issues, the sieve test accounted for 25 per cent of the cost of quality failure. The link between product quality and revenue loss is depicted in figure 2.

**Figure 2. From Low Product Quality to Revenue Loss**



## 1.4 Research Outline

### 1.4.1 Overview

The research study consists of six chapters, starting with the introduction, followed by the literature review, the research design, analysis of the results, discussion and interpretation and finally, the conclusion. These chapters are all designed to give the reader an overall picture of quality and maintenance within the context of this study, and how they come together to answer the research questions.

### 1.4.2 Chapters 1 and 2

The first chapter introduces the study, then states its purpose and identifies the problem statement as well as breaking down the study question into three more explicit research questions. The chapter provides a background on which the research is based.

The next chapter, the literature review, examines other relevant studies that have been done on the same research areas. It examines the production and maintenance philosophies that have developed over time and how they have blended to improve manufacturing. It summarises important findings related to existing research and provides the overall context around which this study is based.

### 1.4.3 Chapters 3 and 4

Chapter 3 covers the methodology that was used to gather and analyse the data required to answer the research questions. It sets out the statistical research method used to analyse documented data. The chapter outlines the testing, carrying out and review of the survey. It also covers all ethical dilemmas and conflicts of interests that were considered and the approvals sort before commencing the study.

The results of the study are objectively presented in the fourth chapter. The aid of statistical analysis and graphical representation is used to summarise the results from correlation software and from the survey.

### 1.4.4 Chapters 5 and 6

Chapter five is the discussion section that provides a subjective interpretation of the results from chapter four. It outlines the important finding from the study related them to answering the research questions. These findings and observations are compared for similarities and differences to the findings of other studies of the same context. This chapter discusses the limitation of the research and points areas of further study.

The study conclusion covering overall research summary is provided in the final chapter. This chapter summarises the research from the research questions, the study design to the results, findings and study limitations. It highlights the importance of the findings and their implications to the industry and further research in a similar context. It recommends avenues that could be followed to test and strengthen the study findings. Lastly it included an insight from the researcher on the overall research context and its importance.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 OVERVIEW

The literature review examines studies in quality and maintenance as separate manufacturing streams. It reviews how these streams have developed and changed during the industrial and technological revolution. And finally looks at research in the reliance of quality on maintenance in relation to product manufacturing and cost cutting. The review will highlight maintenance and production philosophies and their relationship. It will also evaluate inadequacies in these studies in which this research intends to contribute.

A large number of research papers have dealt with the study of quality in general, quality control, quality assurance and the cost of quality in particular. Some have also widely dealt with maintenance strategies in the form of corrective, preventive, predictive and reliability centred maintenance. Quality research papers take into account those practices that have led organisations to focus on lowering the cost without compromising the product quality. Maintenance strategy research papers have extensively concentrated on maintenance philosophies that support the continuous availability of production assets and how to make them more reliable and prolong their life span. Not so many research papers have taken into account the relationship between product quality and maintenance strategies.

## 2.2 QUALITY AND MAINTENANCE OVERVIEW

### 2.2.1 Quality Overview

Over the past century, the desire to make products that conform to pre-determined standards has seen the quality journey move from inspection in the 1900s to Total Quality Management (TQM) in the beginning of the 21 century (Naidu, Babu et al. 2006). This journey has moved from inspection to quality control, quality assurance and then TQM, with most of the credit attributed to countries like Japan and America and people like Edward Deming, Joseph Juran, Philip Crosby, Armand Van Feigenbaum and Kaoru Ishikawa.

During an inspection, products are examined, measured and tested by trained inspectors. The results are compared to specific standards to determine if the products conform before being sold to customers. Inspection is also used to find and correct manufacturing faults, which means this is done after the product has been completed. The desire to prevent the making of defective led to the introduction of quality control.

In quality control, products that did not conform to the standards would be detected and fixed along the production line before they are completed. It was the beginning of the introduction of statistical quality control. In the 1920s Western Electric was trying unsuccessfully to achieve product consistency and conformity. In studying their process Dr. W. Shewhart developed the statistical process control methods of quality management (Kanji 1995). His methods, carried out at various stages of the production process by trained quality control personnel, involved sampling and statistically inferring product conformity with the aim of detecting and controlling quality issues.

These methods took hold and became a planned and systematic everyday activity in most production processes. It became a means of competitive advantage and a way of providing customers and regulatory authorities with confidence that products or goods and services met the required standards. The concept became known as quality assurance. It is defined by two business focal activities; that is, product design and quality control (Evans and Lindsay 2008).

After the end of World War 2, Japanese goods held a reputation of being cheap and of low quality a reputation held by goods made in China in the early 2000s. Japanese manufacturers gradually moved away from this reputation by embracing the total quality concept through Total Quality Management (TQM). Through this concept, quality became the responsibility of everyone throughout the organisation rather than being left to inspection at the end of the process or as a preserve of the quality control department. By the early 80s, Japan was leading the world in the quality of electronic and automotive products. The total quality philosophy improved Japanese products, reduced defects and minimised waste and thus reducing production costs. The rest of the world caught up with the total quality mindset with the establishment of quality management standards.

By the early 1990s, TQM was getting widely recognised and internationally accepted as a part of business models. In an effort to encourage the adoption of quality management in their industries and increase their economic competitiveness, governments in the North America and some European countries developed quality management awards modelled on the TQM concepts. These include among others, the Malcolm Bridge Award in the USA, the European Quality Award in Europe, the Canada awards for excellence and the International Organisation for Standardisation ISO 9001 (Alonso-Almeida and Fuentes-Frías 2012).

### 2.2.2 Maintenance Overview

As the demand for quality increased, manufacturing systems moved from being highly manual with maximum human intervention to being highly automated with minimum human involvement. Less human involvement in the process reduced product variability and increased product consistency (Bullinger, Warnecke et al. 1986). Maintenance strategies have also evolved from highly reactive to highly preventive. This evolution has resulted in lower maintenance costs, increased system availability, reliability and equipment maintainability and performance. Strategic investment in maintenance has led to improved performance in manufacturing processes. This has enhanced the competitive position of many manufacturing organisations (Coetzee 1999; Ahuja and Khamba 2008).

Highly manual manufacturing systems were traditionally run to failure. As more automation was introduced and product quality and consistency became important, machine availability became central to production planning.

This led to changes in maintenance strategies moving away from reactive maintenance (RM) where machines were only repaired when they broke down, to preventive maintenance (PM) (Dhillon 2002). In preventive maintenance, inspections, monitoring, equipment history and equipment manufacturer's recommendations are used to anticipate failures. Then plan and repair the equipment before it breaks down. Condition monitoring and reliability centred maintenance (RCM) are some of the strategies used today to achieve maximum equipment reliability or the probability that the equipment will perform its function under the right conditions for a stated period of time (Dhillon 2002). The effectiveness of maintenance strategies significantly contributes to the performance of equipment, production efficiency and product quality (Macaulay 1988). A cost-effective and high-quality manufacturing process requires that maintenance and production strategies are implemented together.

Maintenance is an inevitable and very significant support function of any businesses that has invested in machinery. It plays an important role in backing up many emerging business and production philosophies like lean manufacturing, just-in-time production, total quality control, total productive maintenance and six-sigma (Pun, Chin et al. 2002). As a result, it is imperative to have effective asset management and maintenance strategies that can positively influence business success factors such as quality, speed, reliable delivery, safety and profitability (Dhillon 2006).

## 2.3 QUALITY

Different researchers, depending on their research discipline and objective, disagree on the definition and the effects of quality on company profitability, productivity and cost (Mitra 2002). Of the four competitive weapons, quality, reliability, delivery and price, quality is the most important and extremely difficult to define and agree on a consensus definition (Hoyer and Hoyer 2001). In most manufacturing environments, products are made so they can be sold to someone for a profit. Milk products are also produced so they can be ultimately used by the consumer. This research will focus on the definition of quality in relation to the company attributes of quality and the end user's expectation of what a quality product is. This section will look at different research papers that have described quality from this context.

### 2.3.1 What is Quality?

There are two distinct but very broad perspectives of the definitions of quality that come from different researchers. These are quality from the customer's expectations and from the manufacturer's conformance standards.

As early as the 1950s, quality was associated with the needs of the customers and the goal of manufacturers to make deficient free products. In their 1945 book Juran's Quality Handbook, Dr Joseph Juran and A Blanton Godfrey described quality as those features of a product that provide customer satisfaction and are free from deficiencies (Juran and Godfrey 1979). The customer is satisfied enough to spend their income on what they perceive as value for money. As the quality of the product gets better, the customers' expectation is also increased and so is the likelihood of selling the goods and doing better than the competitors. In his research on consumer perception of quality, Mitra also incorporates the company's standard and the customer's desire in his definition of quality as the degree to which a product or service satisfies the attribute levels specified by the firm and desired by customers (Mitra 2002). Increasing the quality of the products comes at an expense to the firm and this has to be balanced with the needs of the customer.

Hao Peng describes quality as a product meeting various characteristics and meeting and exceeding customer needs and expectations. These characteristics include technological, psychological, time oriented, cost and product development life cycle (Peng 2010). This reinforces the concept that quality has to satisfy both the manufacturer's, as well as the customer's standards.

The perception of milk powder quality, either by the dairy industry or the consumer, if basically not different from these views. One might argue that the aspect of food safety is far more important than any other characteristic of customer satisfaction. Although different disciplines within the milk powder manufacturing process might view quality as conforming to agreed specifications within their area of influence, they are all aimed at producing an end product which meets satisfaction from the customers' perspective. Therefore, the sum of the firm's agreed distinct specifications should be based on meeting the needs of the customers.

### 2.3.2 Measuring Quality.

How do organisations know what quality standards to deliver that would meet their customers' expectations? In most organisations part of the marketing budget is spent on measuring the performance of the quality aspect of their products and finding out what customers expect from their products. The results are then used to improve product quality. A number of tools are used in measuring product performance. These include surveys and customer feedbacks. Different customers have different perceptions of expectation making it a complex exercise to measure expectation. The most commonly tools used to measure customer expectation is expectancy disconformity (Myers 1991). Most researchers in their study of consumer expectation have focused on Oliver's model in which he argues that consumer satisfaction is a function of both product performance expectation and the degree to which actual product performance departs from expectations (Oliver 1980). Generally most studies that have tested Oliver's model do support his argument (Bettman 1986).

Quality is a multidirectional concept both in theory and practice. It can be described in a variety of perspectives depending on the research paradigm or business discipline (Golder, Mitra et al. 2012). This study researches the relationship between the quality of milk powder, which can be viewed from an operational perspective, and equipment maintenance, which can be viewed from an engineering perspective. In this context, quality means the conformance to agreed design operational and engineering specification, which reflect on the reliability and efficiency of the internal processes.(Feigenbaum 1991).

## 2.4 PRODUCTION PHILOSOPHIES

Production philosophies, strategies and practices such as total quality management (TQM), just in time (JIT) and total productive maintenance (TPM) have similar basic goals of continuous improvement, waste reduction and quality improvement (Ōno 1988; Seiichi 1988). In most manufacturing practices, these strategies are implemented one after another as part of continuous change processes. Some researchers have argued that they should be implemented simultaneously, so that weaknesses in one will be complemented by strengths in another. For example, Philip Huang in his study shows the importance of integrating JIT, total quality control (TQC), factory automation (FA), and TPM with worker participation (Huang 1991). While Kristy et al when studying the relationships between the implementation of TQM, JIT, and TPM and manufacturing performance, demonstrate the importance of implementing the common set of human and strategic practices that are shared by all three programs (Kristy, Kathleen et al. 2001). This part of the literature review examines some of these philosophies and their relationship to product quality.

### 2.4.1 Total productive maintenance (TPM)

Total productive maintenance integrates production and maintenance people and processes in order to achieve ideal manufacturing conditions through efficient equipment and employee engagement. Multi skilled operators are given the autonomy to do maintenance on the machines they operate. This practice is also referred to as autonomous maintenance. The purpose of autonomous maintenance is to develop operators so that they are able to take care of small maintenance jobs on their equipment. This frees time for skilled maintenance technicians to concentrate on value-add activities and complex technical repairs (Venkatesh 2009). TPM describes a relationship between production and maintenance that aims to achieve continuous improvement in product quality, operational efficiency, safety and maximum capacity (Seiichi 1988). Nakajima states that without TPM, the Toyota production system could not function. In their 2001 study on the factors that influence the implementation of TPM and its impact on manufacturing performance, McKone et al found that through just in time (JIT), TPM had a positive direct and indirect relationship with low cost, high levels of quality and strong delivery performance (McKone, Schroeder et al. 2001).

### 2.4.2 Lean Manufacturing

Lean Manufacturing is a production practice derived from the Toyota Production System (TPS) that considers the expenditure of resources for any purpose other than the creation of value for the end customer to be wasteful and should be eliminated (Pappis 2010). Value, as seen from the customer's perspective, is defined as any action or process that a customer would be willing to pay for (Cobb 2011). Lean manufacturing was first coined by John Krafcik in his 1988 article, "Triumph of the Lean Production System". Its objective is to eliminate waste, defined by Toyota as muda (wastes), muri (unevenness) and mura (overload) (Landsbergis, Cahill et al. 1999). Lean Manufacturing was popularised by Womack, Jones and Roos in their book The Machine That Changed The World describing the production practices based on the Toyota Production System (Womack, Jones et al. 2007). Lean's focus on the customer is partly captured in Juran and Godfrey's description of quality as those features of a product that provide customer satisfaction and are free from deficiencies. In the New Zealand dairy industry, Fonterra applies lean principles in its production processes and at their research and development centre, aimed at achieving operational excellence (OE) (van Wagtendonk, Hill et al. 2008).

### 2.4.3 Six Sigma

From the time it was developed by Motorola in 1986 in an effort to increase product quality, Six Sigma (SS) is now extensively used as a quality management methodology. It aims to improve product quality by identifying and removing the causes of defects and variability in the manufacturing processes (Cagnazzo and Taticchi 2009). The six sigma business strategy emerged from the best parts of TQM. The shift from TQM to a Six Sigma strategy is seen as a key to the successful implementation of a quality management system.

The goals of this strategy are in line with Juran and Godfrey's description of quality as those features of a product that provide customer satisfaction and are free from deficiencies.

Six sigma activities extend to all the levels of the organization beyond the manufacturing process. All activities within the company are aimed at reducing cost and producing a high-quality product or service. General Electric (GE) incorporated six sigma, starting from their product design stage. In their 1998 annual report they state that every new product and service in the future will be designed for six sigma(DFSS) (Boothroyd Dewhurst 2000). Product design at GE would be specifically designed using customer feedback. In 2001, half of GE's sales came from DFSS products (Evans and Lindsay 2011). This showed that the six sigma quality focus by the company was paying dividends.

## 2.5 MAINTENANCE BEST PRACTICES

A successful maintenance management program is measured by the elimination or reduction of the six big equipment related losses (Kyōkai 1996). The reduction of breakdowns (1) and setups (2) results in very low equipment downtime and high availability. The elimination of small stops (3) and reduced equipment speed (4), results in the increase in productivity and process yields. The elimination of start-up delays (5) and production rejects (6) results in a dramatic improvement in product quality. The goal of any well-run maintenance organisation is to have the lowest cost of the sum of two quantities; that is, maintenance labour and material as well as production loss (Kelly 1997; Moubray 1997). Production loss includes inability to produce due to equipment break downs and producing low quality products due to inefficient equipment. The elimination and reduction of the six equipment-related losses increases equipment efficiency and lowers maintenance and production losses. Geraerds describes maintenance as all activities that are aimed at keeping equipment in, or restoring it to, a physical state necessary for it to fulfil its production function (Geraerds 1983).

### 2.5.1 Reactive or Breakdown Maintenance (RM)

This is one of the most inefficient maintenance strategies for reliability. It is a very high-cost strategy in terms of maintenance costs and production losses. In reactive maintenance equipment is repaired only after it fails or its performance has severely declined. The strategy was widely used in the 1940s. It has the disadvantages of unplanned stoppages, excessive equipment damage, spare parts problems, high repair costs, excessive waiting and maintenance time and high trouble shooting problems (Ben-Daya 2009). Despite the cost and inefficiency of the strategy, studies show that it is the most widely used in most manufacturing organisations. More than 55% of maintenance activities and resources are spent on reactive maintenance, 30% on preventive maintenance and 12% on predictive maintenance (Gulati, Smith et al. 2009), Figure 3.

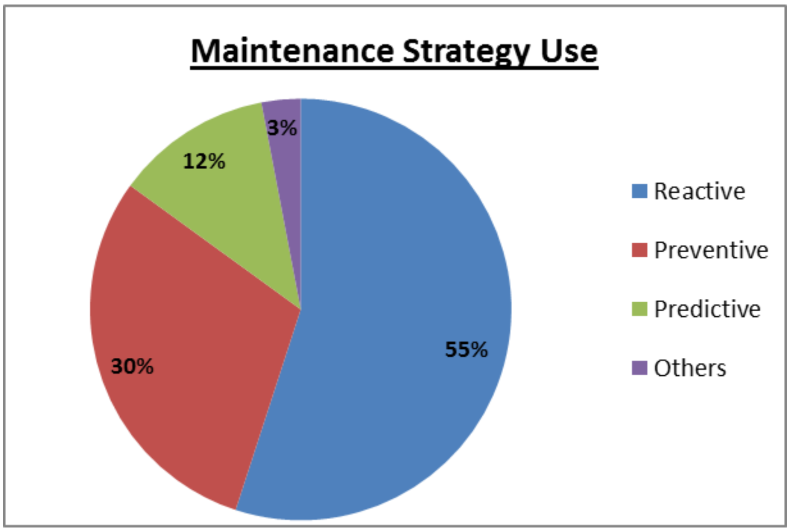



**Figure 3 - Maintenance Strategy Use Distribution**

### 2.5.2 Preventive Maintenance (PM)

Preventive maintenance started to emerge in the early 1950s as a new and improved development from reactive maintenance. Rather than run equipment to failure, preventive maintenance aims to increase equipment availability and reliability by preventing breakdowns and prolonging equipment life. In the execution of this strategy, maintenance activities are undertaken after a specified period of time or amount of machine usage (Gits 1992).

Planning maintenance activities to avoid production disruptions and maintaining equipment before it completely breaks down reduces maintenance costs like labour, parts, downtime and quality. Some of the activities associated with preventive maintenance are planning, inspections, cleaning, adjustments, lubrication and parts replacement. As more preventive maintenance is carried out, the costs of PM rises, but the cost of reactive maintenance falls. The total maintenance costs also goes down until it reaches an optimum level, were increasing PM activities starts to have a negative effect on the overall maintenance cost. Figure 4 shows maintenance cost versus increase in PM and decrease in RM activities. The cost-effective point of balance between preventive and reactive maintenance activities is within range L. (Levitt 2003). Studies indicate that these savings can amount to as much as 12% to 18% on the average over a reactive maintenance strategy (Gregory, Aldo et al. 2004). As much as preventive maintenance is a better strategy than reactive maintenance, it has its own short comings like; it requires more resources to carryout regular PM activities. The strategy cannot eliminate unexpected equipment failures. The carrying out of some PM activities maybe unnecessary and could result in service errors that lower equipment life.

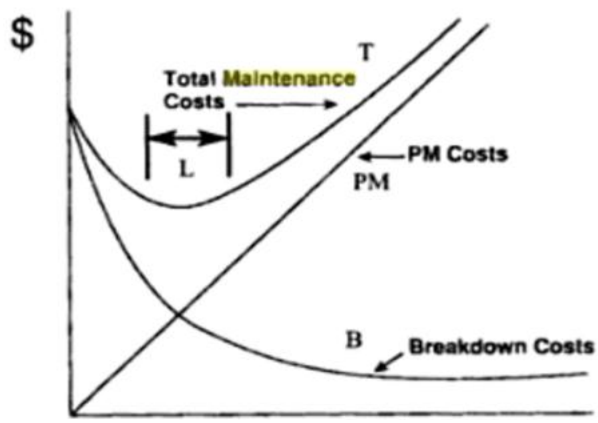



**Figure 4 - Total Maintenance costs due to lowering RM and increasing PM.**
Courtesy of Complete guide to PM and predictive maintenance – J. Levitt.

### 2.5.3 Predictive Maintenance (PdM)

Predictive maintenance, also known as condition based maintenance (CBM), is a maintenance strategy, whose activities are initiated based on the condition of the equipment rather than on a time schedule or amount of machine usage as in preventive maintenance (Beebe 2004). This improves the use of maintenance resources in that only necessary maintenance activities are executed. Equipment will be scheduled for maintenance only when its condition starts to deteriorate. There is less production disruption as equipment can be planned to be taken out of service on evidence of deterioration. Different diagnostic techniques are used to measure the physical condition of the equipment such as temperature, noise, vibration, lubrication and corrosion (Chary 2004). These are depended on the condition that needs to be monitored. Temperature is used to detect loose electrical connections, damaged insulation or lack of ventilation. Vibration analysis is used to detect misalignment, rotation imbalance, bent shafts or damaged bearings.

### 2.5.4 Reliability Centered Maintenance (RCM)

Moubray described it as a process used to determine what must be done to ensure that any physical asset continue to do what its users wanted it to do in its present operating context (Moubray 2001). Introduced in the late 1970s by the United States Department of Defence, it is a logical process for developing and achieving the highest level of reliability that can be achieved through an efficient maintenance strategy(Scott 2000). RCM is executed by identifying the critical production or functional assets, understanding the causes and effects of their failures so as to determine appropriate maintenance strategies. Structured problem solving tools used in RCM include failure mode and effect analysis (FMEA), Failure mode effect and criticality analysis (FMECA), Root Cause Analysis (RCA), Physical Hazard Analysis (PHA), Fault Tree Analysis (FTA), Optimizing Maintenance Function (OMF) and Hazard and Operability (HAZOP) Analysis (Ben-Daya 2009). Predictive maintenance is the strategy dominantly used to achieve RCM goals with an added advantage of improving reliability at low costs by closely matching limited resources to maintenance needs.

Although it requires expensive training and equipment to start up, it is an efficient strategy with long-term low costs. It eliminates unnecessary maintenance and reduces the chances of unexpected equipment failures.

### 2.5.5 Measuring Reliability

Equipment reliability is measured by how consistent the equipment or plant can perform its intended function. The uptime can be defined as mean time between failure (MTBF) for repairable equipment or mean time to fail (MTTF) for non-repairable equipment (Charantimath 2003). Long MTBF indicates a reliable system, while short MTBF failure indicates an unreliable system. To produce quality products a plant must not only be available but must be reliable and efficient. If a plant is designed to run in automatic mode for accuracy and concistency, but is forced to run in manual mode, with human intervention, because of faults in the automation system, accurracy and consistency are no longer guaranteed. The system might still be available but is no longer reliable. The formula for calculating reliability of a system over time (t) is shown in Figure 5 (Charantimath 2003).

$$R(t) = e^{-t/MTBF}$$

**Figure 5 - Formula for Calculating Reliability**

### 2.5.6 Measuring Availability

Availability defines the average time the equipment or plant is availabe for use and is mainly used to determine how much preventive maintenance is required on an equipment. MTTR defines the average amount of time between equipment failure and restoration to full functionality. This time includes failure observation, fault diagnosis and equipment repair (Kahng, Goto et al. 2004). It can be used for cordinating plant stoppages between maintenance and production.

The formula for calculating percentage availability or the time the equipment is in a functional state using MTBF and MTTR is shown in Figure 6 (Stapelberg 2008).

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100$$

**Figure 6 - Formula for Calculating Availability**

## 2.6 Quality and Maintenance Relationship

Quality management philosophies such as Total Quality Management (TQM) or Toyota Production System (TPS), have made quality control part of the manufacturing process, rather than leave it to the end of the production line. This makes it easier and quicker to identify defects at the source and take action immediately to eliminate them. According to Deming, defects are not free. Somebody makes them and gets paid for making them (Deming 2000). If the defects are equipment related a link with the machine design, maintenance or operation can be clearly and immediately isolated and dealt with. Maintenance strategies are no longer exclusively prioritising asset availability, but include other factors such as reliability, efficiency, safety and quality.

The impact of asset reliability on throughput has been well researched, but the relationship between maintenance and quality is not clearly established (Gheriani 2008). This statement is also supported by Ben-Daya and Duffuaa in their research on Maintenance and Quality. They concluded that the link between maintenance and quality, although not completely missing, is not adequately addressed (Ben-Daya and Duffuaa 1995).

Using Pearson's correlations analysis to identify key contributors to manufacturing unscheduled equipment downtime in USA factories, Hop Nguyen, in his research, The Relationship of Equipment Reliability Maintenance Allocation to Productivity and Quality, documented a significant link between unscheduled downtime and late product deliveries (Hop 2011). He shows that changes in maintenance planning were associated with a significant lowering of unscheduled downtime and subsequently, a lowering of late deliveries.

### 2.6.1 Cost of quality.

By analysing the causes of cost of quality failures and causes of equipment failure a relationship can be established. The development of efficient maintenance strategies that improve system performance require establishing the mathematical relationship between maintenance and both quality and cost of quality (Ahmed 2008). Cost of quality failure analysis enables the identification, measurement and correction of the causes of poor quality, be they machine or human related. Crosby suggests that the cost of quality must be quantified by its different causes, like rework, wrong specifications, scrap, downgrades, inspection or testing and build a quality awareness program within the whole organization (Sallis 2002). This awareness program must be well emphasised within the maintenance department as they play a direct and critical role in the success of quality improvement strategies like TPM, PM and PdM. Improved awareness is the start of cultural change towards quality improvement. The relationship between the quality-related costs of prevention, appraisal and failure (P-A-F) (Feigenbaum 1991) and quality awareness and improvement are shown in Figure 7. As the awareness and subsequent improvement increase, quality-related costs like the cost of preventing defects and ensuring that equipment and people provides quality goods, and services decreases.

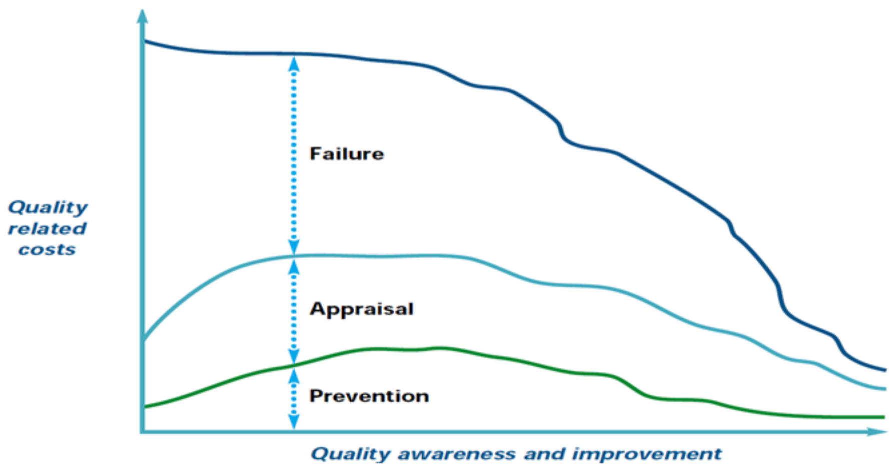



**Figure 7 - PAF model - Increased Awareness = Low Quality cost**

Courtesy of UK Parliament Depart of Trade and Industry.

### 2.6.2 Maintenance and quality costs

The PAF model has been adopted by the American Society for Quality (ASQ) and by the British Standard Institute (BSi). It is the most frequently used quality cost model by companies (Schiffauerova and Thomson 2006). According to the British standard BS4778: Part 2; ISO 8402 quality-related costs are the expenditure incurred in defect prevention and appraisal activities plus the losses due to internal and external failure (Bs 1991). Maintenance is one of the activities that is carried out to prevent or reduce the risk of nonconformity or defect. Therefore, maintenance contributes indirectly to lower or eliminating opportunity costs due to loss of business as a result of manufacturing defects. Figure 8 shows that as the defects approach zero so do failure costs. Efficient maintenance strategies contribute to the reduction of quality-related cost and overall total cost of quality.

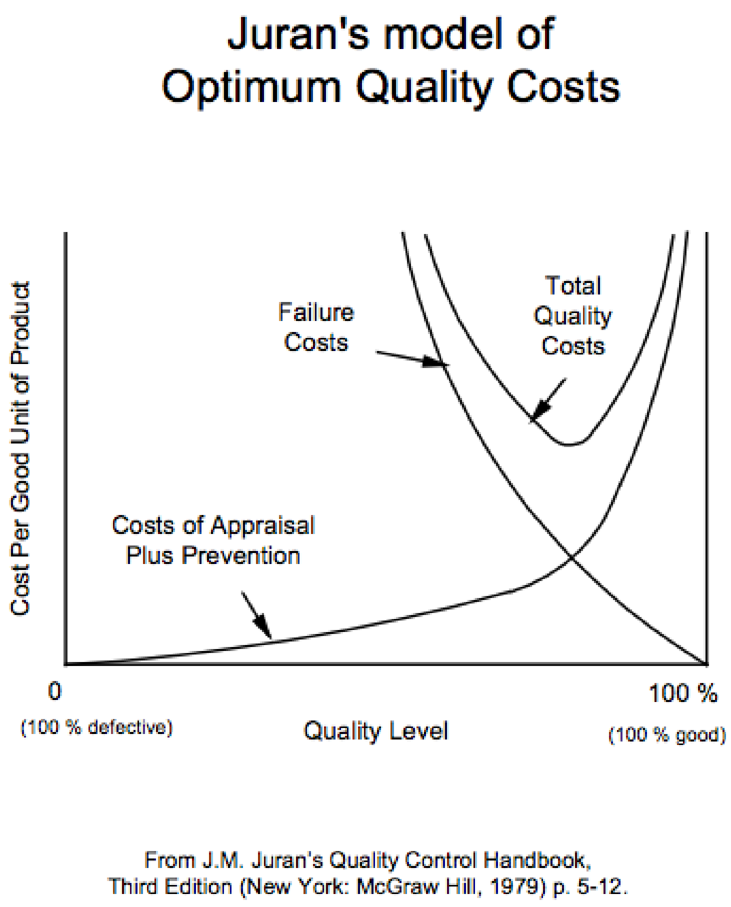



**Figure 8 - The Relationship between Quality and Quality Costs**

The relationship between maintenance and quality costs is illustrated by an example from USA's Midwestern steel mill that produced flat-rolled, low-carbon steel for the automobile and appliance markets.

The steel mill performed an electroplating operation that deposits metallic zinc on to the steel substrate. On one occasion, the wipers that contact the surface during plating wore beyond an acceptable level. Maintenance workers improperly replaced the wipers with ones made of a different material. This deviation caused the customer to incur failure costs for problems it experienced from wiper material embedded in the steel surface. The alternative material reduced the steel mill's preventive maintenance costs; but the costs of identifying the problem, reworking automobile bodies after painting, and regaining the customer's goodwill were enormous. Thus, an improperly performed maintenance activity intended to reduce maintenance costs resulted in an enormously high-quality failure cost (Weinstein, V. et al. 2009).

### 2.6.3 Summary

In this chapter some of the research related to production and maintenance philosophies aimed at improving product quality were discussed. The chapter followed the development of these theories as they responded to greater demand for better quality, low-cost and highly competitive environment throughout history. These quality improvement strategies base their success on the involvement of all employees within the organisation, from the CEO to the shop floor. Most of the maintenance philosophies were developed with a focus on reliability, availability, low-cost and efficiency.

# Chapter Three: Research Design

## 3.1 Introduction

After establishing the objectives of the study in chapter 1 and reviewing the relevant research literature in chapter 2, this chapter will set up the research design required to answer the study questions. It will also establish the road map for the appropriate research methodology, data collection, calculation and analysis. It is the blueprint for fulfilling study objectives and answering the research questions(Cooper and Schindler 2006).

## 3.2 Assumptions

Certain underlying assumptions were necessary in the collection and analysis of data for this study. Electronic and hard copy archived production and maintenance data was gathered from Plant A. The plant has 6567 assets, executed 1000 work notifications and producing 130 697 metric tons of milk powder over the sampled period. The data collected is assumed to be an accurate representation of a normal production season. It was collected with the written approval of the company's management (Appendix L).

## 3.3 Research Methodology

This is a quantitative analysis research, where production and maintenance data collected will be subjected to correlation analysis to see if there is a cause and effect relationship between maintenance activities and production output. To answer the research questions, effects on the production outcomes will be focused towards effects to product quality, quality losses and cost of quality failures.

As identified in the literature review, high awareness and engagement on quality issues within the maintenance department will drive behaviour towards contribution to product quality initiatives. A survey was carried out within the maintenance department to gauge the level of awareness of the team's contribution to the effects of their work to product quality and cost of quality.

Appendix B shows the likert scale with the statements used in the survey. A test survey was carried out on a small selected number of 10 people as a pilot test to establish if the questions asked and the answers given will adequately answer the research question. The purpose of the pilot study was to detect potential weaknesses in the design of the survey instrument before it is deployed to the general sample (Cooper and Schindler 2003). The final survey questionnaire was given to sixty people out of a population of 70 giving a contact rate of 85.7%. These people were chosen due to their availability and ease of access at the time of the survey. Of the sixty people given the survey, 46 responded, giving a 76.7% cooperation rate. The response rate, that is, the product of the contact rate and the cooperation rate was 67.7% (Groves and Couper 2012). The high response rate leads to a higher probability of the survey responses being representative of the overall population (Buchanan and Bryman 2009).

Archived production and maintenance data for the F12 season, collected from the company's data bases and Computer Maintenance Management System (CMMS), will be subjected to quantitative analysis using IBM's Statistical package for the social science (SPSS). The statistical conclusion obtained would help to answer some of the explicit research questions. Figure 9 summarises the relationship between the research question, the type of data collection and research method that will be used to answer the question.

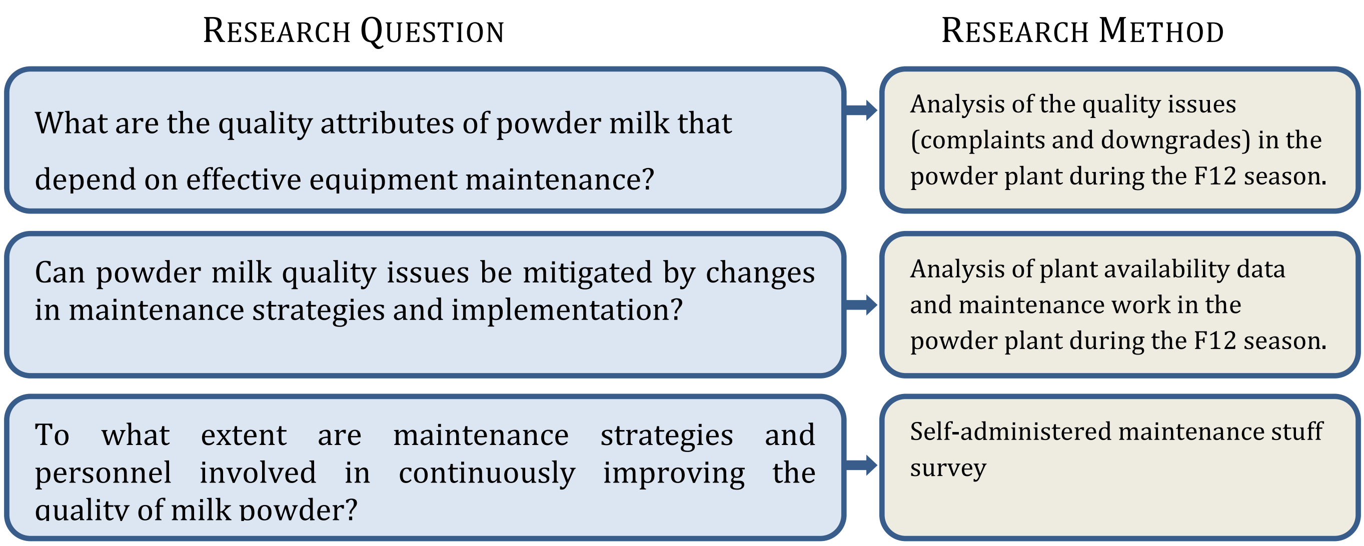



**Figure 9 - Research Question and Selected Data Collection**

## 3.4 Data Collection Method

The data collected for this research is based on both production records during the August 2011 to July 2012 (F12) season and human perception of quality awareness within the maintenance department. Due to time constraints and the non-availability of some of the records from previous years, production data for this study was confined to the F12 season. Product Quality Deficiency Reports (PQDR) and cost of quality financial data were sourced from production sections of plant A that oversee product quality initiatives and from the company's archival database. The data retrieved was categorised into two main sub-groups, namely maintenance data and production data. Table 1 summarises the type of data collected from maintenance and production archives for the F12 season. Some of this basic data was filtered to focus on the data that has some relationship with the research context. This was done without ignoring data that might have indirect relevance to the study. For example, product downgrade data was filtered to extract only downgrades caused by equipment failures and downgrades caused by operational errors was not used.

| Research data collected for F12 Season –Powder Plant. | |
|---|---|
| **Maintenance Data** | **Production Data** |
| • Powder Plant number of assets | • Total metric tonnes of powder produced. |
| • Number of Work orders executed. | • Product downgrade data |
| • Planned Preventive Maintenance (PM) | • Customer Complaints data |
| • Unplanned Reactive Maintenance (RM) | • MTBF |
| • Corrective Maintenance (CM) | • Planned and Unplanned stoppages |
| • Automated Plant Availability (APA) | • Cost of Quality Failure (COQF) |

**Table 1 - Data Collected from Maintenance and Production**

## 3.5 ETHICAL ISSUES

The appropriate Massey University Ethics Committee process was followed and adhered to from the beginning to the end of this research. The nature of information gathering and research was considered as having low potential for ethical dilemmas, conflict of interest and harm to participants. A Low Risk Notification (LRN) application was applied for, and approved (Appendix K). To ensure the quality and integrity of this research, the following was taken into account when gathering survey information. The survey participation was voluntary and anonymous. Participants were given an information sheet with the survey specifying that their anonymity and the confidentiality of information sourced will be respected and maintained (Appendix A).

# CHAPTER FOUR: RESULTS AND ANALYSIS

## 4.1 INTRODUCTION

This chapter objectively presents the data collected from the maintenance data base and production archives for the 12 months from August 2011 to July 2012. It also examines the survey assessment intentions and presents the survey results. A statistical analysis was used with bivariate data to determine the correlation between the maintenance data and production data, the results of which are included in this chapter. For example, to determine the relationship between maintenance activities and product quality outputs, the correlation between equipment-related plant stoppages and product downgrades was analysed. The correlation results between the number of breakdown work orders and the number of customer complaint was also examined.

## 4.2 DATA PRESENTATION.

Starting from the measurement metric used to determine cost of quality failures, like downgrades and complaints, a list of all necessary plant data that may contribute to these failures was gathered from the plant's weekly data and compiled into monthly records. Table 2 shows the results of monthly production records for the number of planned and unplanned plant shutdowns, run hours, and mean time between failures. It shows the amount in metric tonnes of milk powder produced per month and how much of it was downgraded in tonnage and per cent age. Also included is the number of complaints per months by tonnage, cost and the number of equipment related complaints.

| Production Data - F12 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | All Unplanned Shuts | All Planned Shuts | Total Run (hrs) | Quantity Downgraded (T) | Quantity Manufactured (T) | % Total to Downgrades | Number of Complaints | Complaints (T) | Complaints ($) | Equip Rel Complaints | MTBF (hrs) |
| Aug | 20 | 35 | 730 | 69 | 6764 | 1% | 15 | 5751 | $473,768.11 | 5 | 3 |
| Sept | 35 | 47 | 718 | 680 | 13812 | 5% | 17 | 538 | $82,847.13 | 11 | 20 |
| Oct | 6 | 56 | 746 | 607 | 14867 | 4% | 7 | 2 | $3,646.40 | 6 | 9 |
| Nov | 13 | 56 | 742 | 269 | 14429 | 2% | 32 | 901 | $11,899.52 | 22 | 6 |
| Dec | 12 | 49 | 721 | 449 | 15024 | 3% | 26 | 1510 | $13,183.98 | 12 | 13 |
| Jan | 17 | 38 | 744 | 941 | 14943 | 6% | 81 | 9563 | $32,941.13 | 20 | 13 |
| Feb | 6 | 39 | 695 | 320 | 14130 | 2% | 49 | 4803 | $31,342.25 | 28 | 6 |
| March | 18 | 51 | 746 | 1035 | 14843 | 7% | 42 | 1093 | $1,079,408.37 | 25 | 28 |
| April | 3 | 45 | 748 | 1 | 14571 | 0% | 64 | 2093 | $21,604.01 | 40 | 1 |
| May | 15 | 29 | 685 | 0 | 5921 | 0% | 57 | 515 | $265,114.59 | 31 | 3 |
| Jun | 0 | 0 | 0 | 0 | 0 | 0% | 34 | 1301 | $25,454.09 | 27 | 0 |
| Jul | 1 | 15 | 92 | 0 | 0 | 0% | 27 | 283 | $30,008.18 | 21 | 0 |

**Table 2 - F12 Monthly Production Data**

Table 3, depicts monthly data of maintenance activities within the plant. The data was also put together using daily records from the company's Computer Maintenance Management System (CMMS). It includes the number of maintenance related unplanned plant stoppages and the corresponding number of hours for each month. The number of breakdown maintenance (RM) activities, the number of planned preventive maintenance (PM) activities and planned corrective maintenance (CM) activities for each month are also included.

| Maintenance Data - F12 | | | | | |
|---|---|---|---|---|---|
| Month | Maint Rel Unplanned Shuts (#) | Maint Rel Unplanned Shuts (hrs) | Number of Breakdowns (RM) | Number of Preventive Maint(PM) | Number of Corrective Maint (CM) |
| Aug | 7 | 208 | 63 | 43 | 38 |
| Sept | 35 | 1213 | 51 | 25 | 15 |
| Oct | 6 | 560 | 48 | 24 | 19 |
| Nov | 13 | 367 | 43 | 24 | 43 |
| Dec | 12 | 754 | 23 | 14 | 26 |
| Jan | 11 | 771 | 28 | 37 | 48 |
| Feb | 6 | 333 | 42 | 26 | 32 |
| March | 18 | 1173 | 35 | 16 | 24 |
| April | 3 | 554 | 19 | 34 | 42 |
| May | 5 | 168 | 12 | 62 | 18 |
| Jun | 0 | 0 | 0 | 0 | 0 |
| Jul | 0 | 0 | 0 | 0 | 0 |

**Table 3 - F12 Maintenance Data**

The plant received 451 complaints costing over 2 million dollars. Complaints included a number of issues like damaged packages, foreign matter in product and documentation errors as shown in Appendix F. Complaints were generally low throughout most of the year and were unusually high in March and August. Figure 10 shows the complaints that were perceived to be plant equipment related. These were complaints that were recorded as foreign matter and damaged. The rest, such as document error and shipping were excluded.

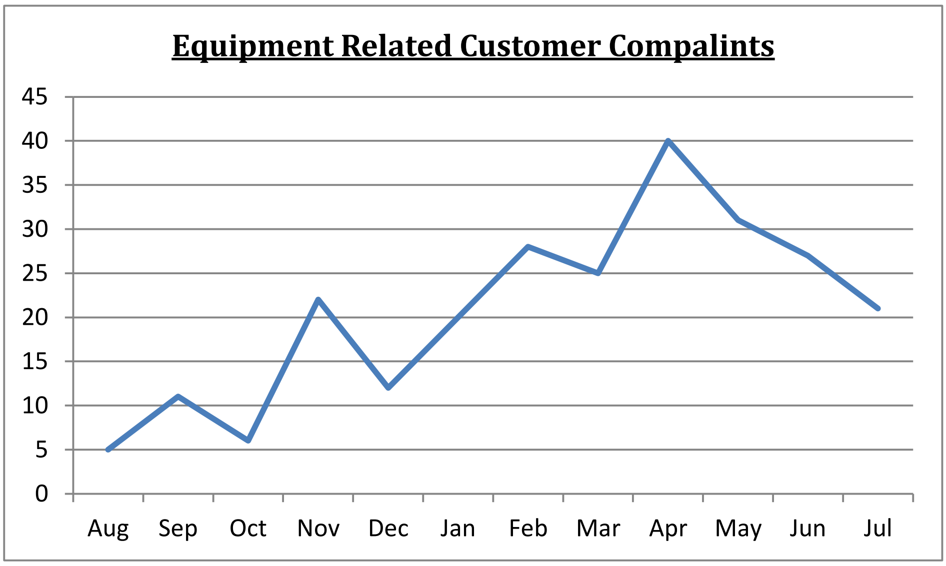



**Figure 10 – Equipment Related Customer Complaints**

The upward trending of the graph from October to April follows a delayed rising milk volume trend from August to November (Appendix H). This may be caused by the time difference between product manufacturing, which peaks towards the end of October, and the time the milk gets to the customer and then factory receiving the customer's complaint.

Figure 11 shows the amount of downgraded powder, that is, product which did not meet the plant's own minimum standards. 4371 tonnes of powder were downgraded during the F12 season due to various reasons like sieve test, wettability and miscibility. The correlation analysis of maintenance based activities such as unscheduled shutdown and preventive maintenance to product downgrade will help to determine if there is a relationship between these variables.

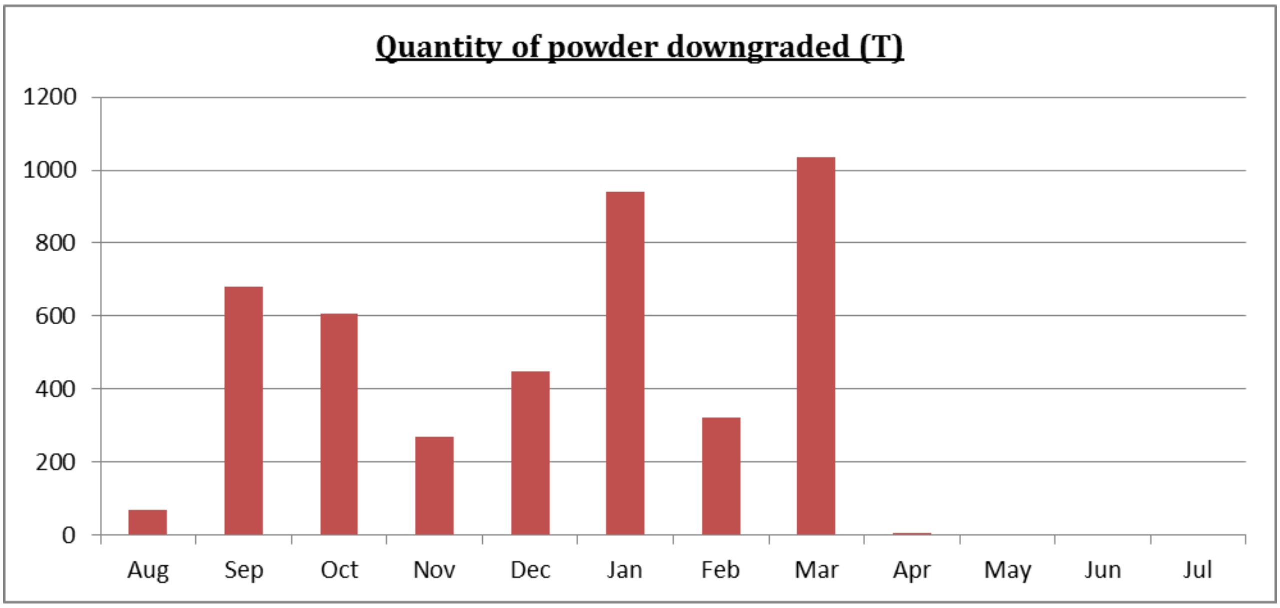



**Figure 11 - Milk Powder Downgraded During the Season**

The mean time between failure graph shown on figure 12 is a measure of the average failure-free operation during each month of the period between August 2011 and July 2012. During November, the plant ran an average of about 16 hours of the 24 hour daily run. This number is much less during the months of February to July as there is less milk supply and the plant is not operational for the whole 24 hours. MTBF is the most accurate predictor of the reliability of the plant and an indirect indicator of the effectiveness of maintenance strategies.

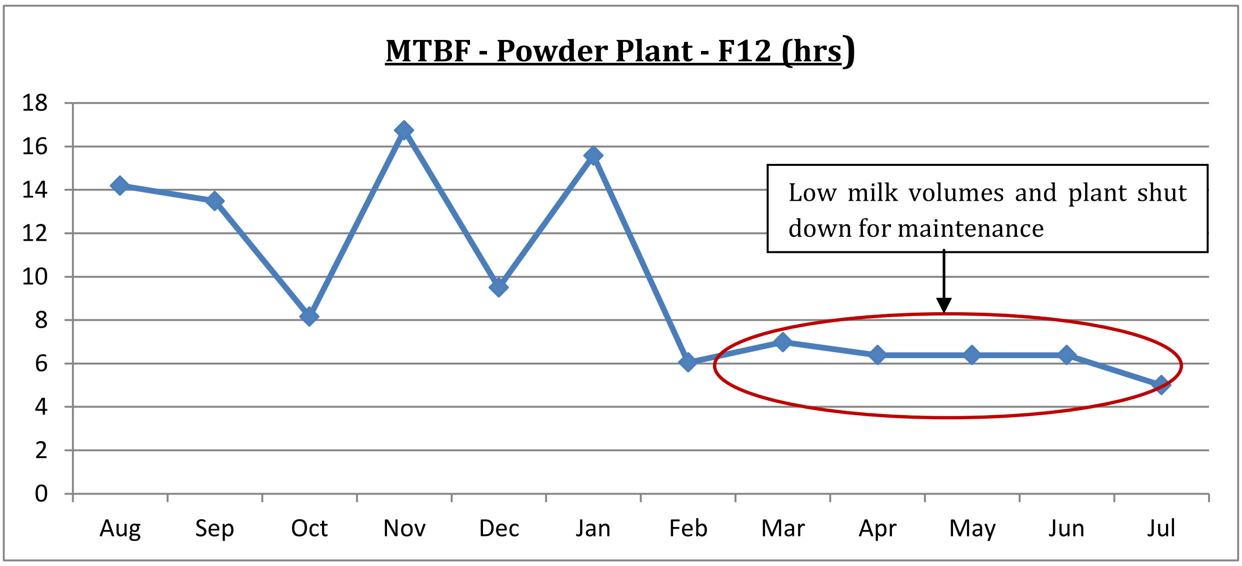



**Figure 12 - Plant Mean Time between Failures**

Automated plant availability data from the company's archives shows the times and causes of unscheduled plant stoppages during a production run. Going through these records showed that some stoppages were caused by operator errors and some by power cuts. Figure 13 shows only plant stoppages that were due to maintenance-related activities like electric faults, mechanical breakdowns and automation faults.

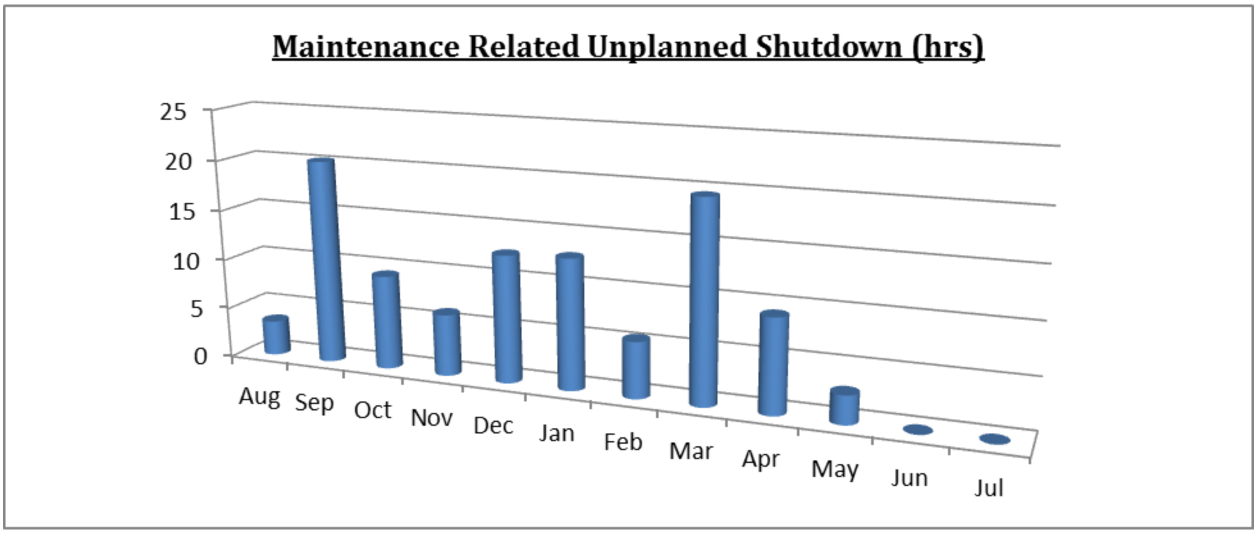



**Figure 13 - Plant Shut Downs due to equipment failure**

364 reactive maintenance and 305 preventive maintenance work orders were recorded during this period, a 54% to 46% ratio. Another 305 corrective maintenance work orders were also carried out (Appendix G). This is equipment repair work that was done during production windows of opportunity without affecting the plant's production schedule. Figure 14 shows the different amounts of reactive and preventive maintenance done in the plant by month. The rising number of preventive maintenance starting from March 2012 indicate the slowing down of milk volumes (Appendix H) and the start of the shutdown maintenance program

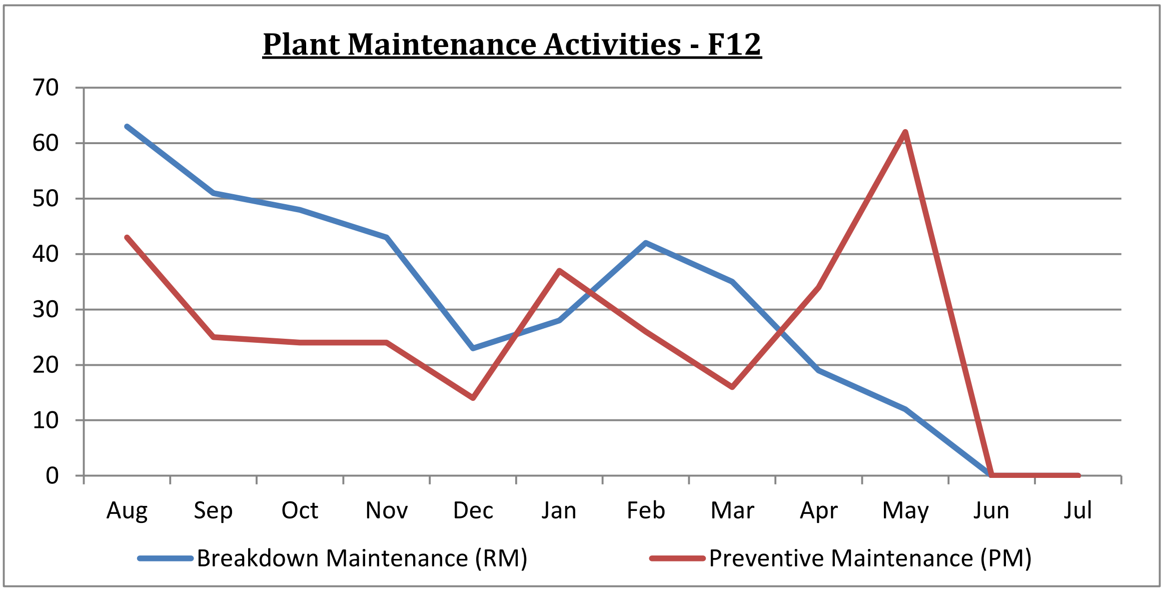



**Figure 14 - Preventive and Reactive Maintenance Activities**

## 4.3 DATA ANALYSIS

To determine if any maintenance activities or lack of, affects the number of equipment related customer complaints, a correlation was calculated between the number of equipment related complaints and maintenance variable like, number of breakdowns, mean time between failures, preventive maintenance and corrective maintenance. The results of the correlation are shown in table 4. The variables have also been compared to other production variable likes planned and unplanned plant stoppages. No correlation exists between equipment related customer complaints and any of the maintenance or production variables. Comparing the same data using a scatter chart (Appendix J) shows that between the months of December to July, there is a decrease in both production and maintenance variables. This may be due to decreasing milk volume (Appendix H) starting in December until end of production in June. These results show that for the recorded customer complaints, none can be categorically traced back to have been caused by any maintenance related issues. The null hypothesis is that there is no correlation

| Correlations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | All Unplanned Shuts | All Planned Shuts | Equip Rel Unplanned Shuts | MTBF (hrs) | RM | PM | CM |
| Equip Rel Complaints | Pearson Correlation | -.436 | -.264 | -.206 | -.482 | -.594* | .087 | .064 |
| | Sig. (2-tailed) | .156 | .406 | .520 | .113 | .042 | .788 | .844 |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | | | | |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | | | |

**Table 4 - Equipment Related Customer Complaints Correlation**

The rest of the data presented in figures 10 to 14 was subjected to a correlation analysis to determine if any of the production data is dependent on any of the maintenance activities. Appendix I displays the results of the analysis for all the variables. The correlation between equipment related unplanned plant stoppages and downgraded products has a strong Pearson's correlation coefficient of r = 0.853 with a very high significance, p-value = .000, table 5.

| Correlations | | | |
|---|---|---|---|
| | | Maint Rel Unplanned Shuts (hrs) | Total Downgrades |
| Maint Rel Unplanned Shuts (hrs) | Pearson Correlation | 1 | .853** |
| | Sig. (2-tailed) | | 0 |
| Total Downgrades | Pearson Correlation | .853** | 1 |
| | Sig. (2-tailed) | 0 | |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | |

**Table 5 - Correlation - Equipment Related Stoppages and Product Downgrades**

Comparing the relationship between these variable using a trending scatter chart shows that as the number of plant equipment failures goes up the amount of downgraded product also rises, figure 15.

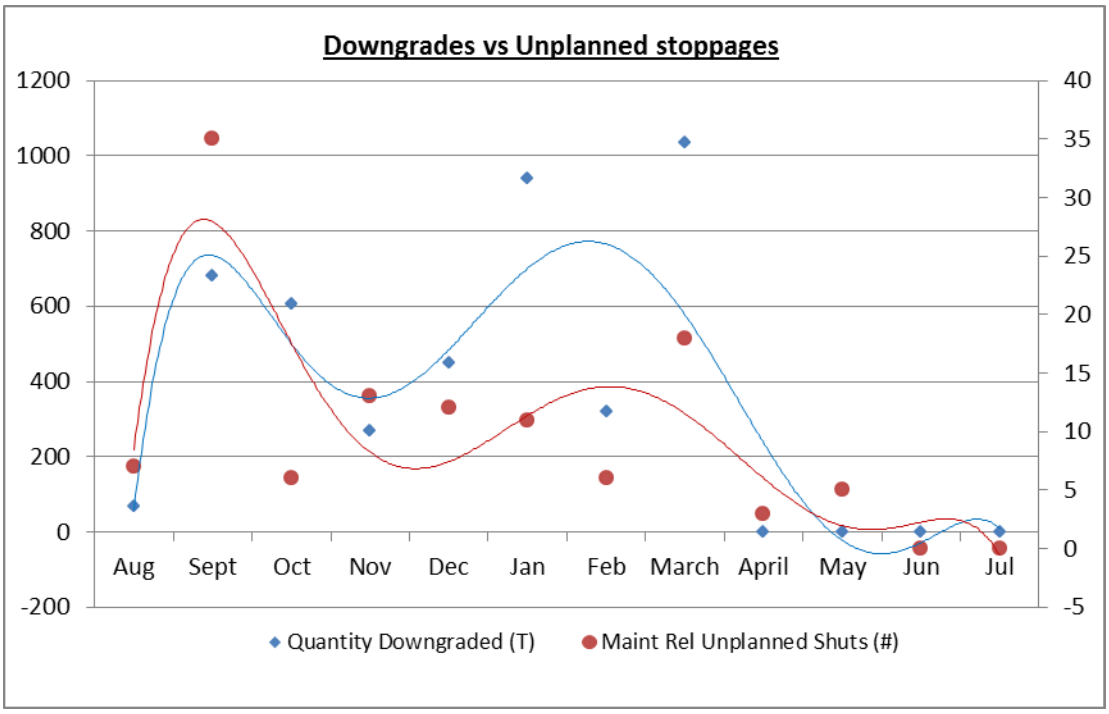



**Figure 15 - Product Downgrades (T) vs. Equipment related stoppages.**

## 4.4 Survey Assessment.

The awareness survey contained eight questions on a likert scale intended to study the extent of awareness within the maintenance department of the contribution maintenance personnel, equipment and strategies make to product quality (Appendix B). Question 1 was intended to assess the employees' awareness of quality issues and whether the overall department has a contribution to make to mitigate these issues. Question 2 was intended at making the employees think about the equipment and how it can contribute to resolving product quality issues. Question 3 was intended at assessing the department's strategies and their contribution to mitigating quality issues from the employee's perspective. Question 4 assesses how far employees are prepared to assist production staff in mitigating one of the six big losses; that is, setup and adjustments. This question indirectly gauges the level of employee engagement and whether they view quality as a production issue or everyone's concern.

Question 5 intends to get the employees to think about the quality of their work, whether it has any effect on product quality and gauge if the department is doing well or has room for improvement in this area. As the co-operative spirit is one of the company's values, question 6 intends to find out if a good or bad relationship between maintenance and production will ultimately affect product quality. Question 7 has two dimensions of assessment. One, that there is a recognition within the department which areas of the plant are critical for product quality and two, that spare parts are readily available for these areas. Lastly question 8 assesses the level of support given to building a culture of making quality an everyone's issue from the employee's perspective.

### 4.4.1 Survey Results

Table 6 summarises the survey results with the full results shown in Appendix C. The vast majority of the maintenance department, 96%, either strongly agree or agree that the overall department has a contribution to make to mitigate product quality issues in the powder plant. The vast majority, 92%, also strongly agree or agree that the quality of maintenance or how well the equipment is maintained does contribute to resolving or worsening product quality. Only 35% of employees agree that the current strategies or their implementation adequately service the areas of the plant critical to product quality. 79% or respondents strongly agree or agree that maintenance can work with production in setting up and tuning equipment for maximum efficiency. The response to question 5 shows that 67% of employees would like to see work and relationship standards improve. This is supported by the response to question 6, where 97% of responders agree that good relations between maintenance and production will have a positive effect on product quality. There is relatively high consensus amongst the respondents to question 5 and 6 as shown by narrow bell shapes of their Gaussian distribution curves in Appendix D or their low standard deviations shown in Table 6. 41% of maintenance staff believes that management does emphasise the importance of maintenance to product quality, in other word management promotes the culture of quality as everyone's responsibility.

| | Question | SD | D | N | A | SD | Mean | Standard Deviation |
|---|---|---|---|---|---|---|---|---|
| **Q1** | The maintenance team has a contribution to make in product quality | 0% | | | 48% | 48% | 4.4 | 0.7 |
| **Q2** | The quality of equipment maintenance has an effect on product quality | 0% | | | 46% | 46% | 4.0 | 0.7 |
| **Q3** | Current maintenance regimes (Preventive, corrective maintenance. etc.) adequately cover production area that directly affect product quality | 2% | | 43% | 35% | | 3.2 | 0.8 |
| **Q4** | The maintenance team has a role to play in the setup and tuning of equipment to achieve the best quality product. | 2% | | | 46% | 33% | 4.0 | 1.0 |
| **Q5** | The standard of maintenance both technical and customer relations can be improved so as to improve product quality | 0% | | 26% | 67% | | 3.8 | 0.5 |
| **Q6** | The co-operative spirit between the maintenance team and production teams has an effect on product quality | 0% | | | 54% | 43% | 4.4 | 0.5 |
| **Q7** | Spare parts that affect product quality are always available when needed. | 15% | 50% | 24% | | | 2.3 | 0.9 |
| **Q8** | Company management emphasises the importance of maintenance to product quality. | 0% | | 35% | 41% | | 3.4 | 0.8 |

**Table 6 - Summary of Survey Results**

The highest mean results are for questions 1 and 6 meaning that a significant number of employees agree or strongly agree that maintenance has a contribution to make in improving product quality. They are also of the view that the cooperative spirit that exists between production and maintenance personnel has a positive impact on product quality. This survey results supports the notion that TPM, whose success is highly depended on this good working relationship, can improve product quality and reduce the cost of quality failure.

# CHAPTER FIVE: DISCUSSION

## 5.1 LIMITATIONS.

Research data was collected from company records for the 2011-2012 production season and is assumed to be correct and representative of all past and future productions seasons. The accuracy of the data, particularly the data that was manually fed into the system, depends on the accuracy, experience and skills of the people who entered the data. Due to time constraints and the non-availability of all necessary data going back to 3 to 5 years the data used was for one season only. Customer complaints data may not all be in sync with the seasons under study, as some complaints, although recorded this current season may be for product manufactured during the previous season. Customer complaints recorded as damages, although not specified what the exact damage was, was assumed to be equipment related.

## 5.2 RESEARCH QUESTIONS DISCUSSION

Research questions specifically focus on the purpose of the study (Creswell 2002). The following sections will use the results and analysis from the previous chapter to answer the three research questions from chapter 1. The objective of answering these three questions is to provide an explanation for the initial study hypothesis. In order to establish if there is a relationship between product quality and maintenance strategies in the plant under study, question 1, distinguishes those attributes that are considered by the plant as a measure of quality. By collecting and analysing production data related to these characteristics, question 1 can be answered. Question 2, can powder milk quality issues be mitigated by changes in equipment maintenance strategies and implementation? Seeks to establish those maintenance activities that contribute directly to production data linked to product quality. The engagement of maintenance staff becomes a critical part of the equation in answering question 3. Question 3 determines if their awareness or lack of has had any contribution or will have any contribution in the future to improving product quality.

### 5.2.1 Research Question 1

The 7.5 million dollars of cost of quality failure recorded by the plant, list three major areas considered as failure indicators. These are product downgrades, product on hold and customer complaints. These have been broken down to identify the various causes of each characteristic. Products downgrades have included both human and machine factors such as sieve test, bulk density, wettability, miscibility and low protein. Customer complaints are also due to a variety of plant related and shipping related issues. These include scorched particles, foreign matter, shipping and bag damages.

In this study different causes of downgrades have been identified and segregated between machine or equipment related and others. It is the equipment related issues that have been a focus of the study as these are considered to have a direct or indirect relationship with maintenance activities. The segregation of complaint issues between plant related and others was not so straight forward, as most issues were recorded as damages without any specifics of whether this was a product related or a packaging damage. Customer complaints and product downgrades were identified as the principal attributes of products quality that could be used in this study.

### 5.2.2 Research Question 2

Equipment related plant shut downs, Appendix E, as recorded and filtered from the automatic plant availability records shows a fundamental link with maintenance strategies. Research findings show that there is significant correlation between product downgrades and equipment related unscheduled stoppages. Months that show high levels of plant stoppages due to mechanical, electrical or other maintenance related faults, also recorded a high level of product downgrades. Because product downgrades are one of the direct indicators of high cost of quality failure, reducing the number of unplanned maintenance related plant stoppages will reduce quality costs.

Research findings also show that reactive to preventive maintenance activity ratio was 54/46 per cent for the season (Appendix G). This is far from the desired 20/80 per cent ratio (Wireman 2003). Finding also show that for the most part of the production season, that is, the period between November and April, there is a strong correlation, .978, with a very high significance, .000, between preventive maintenance and corrective maintenance, figure 19. Corrective maintenance is a result of preventive maintenance activities (Levitt 2003).

| Correlations | | | |
|---|---|---|---|
| | | PM | CM |
| PM | Pearson Correlation | 1 | .978** |
| | Sig. (2-tailed) | | .000 |
| | N | 12 | 12 |
| CM | Pearson Correlation | .978** | 1 |
| | Sig. (2-tailed) | .000 | |
| | N | 12 | 12 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | |

**Table 7 - Correlation - Preventive Maintenance to Corrective Maintenance**

Increasing the preventive maintenance to reactive maintenance ratio to 80/20 will make it possible to find potential faults and fix them before they become a breakdown. This will reduce the number of breakdowns and unscheduled stoppages resulting in reduced product downgrades. Low product downgrades means low cost of quality failures. This correlation shows that powder milk quality issues can be mitigated by changes in equipment maintenance strategies and how they are implementation.

### 5.2.3 Research Question 3

Total productive maintenance requires that the maintenance teams work with production teams to determine which maintenance activities can be performed by operators. The findings from the survey within the maintenance team are a good indicator of how the team views its involvement in the production process and to what extent they think their work has an effect of product quality. The high responses to questions 1 and 2 indicate that the maintenance team has a very high level of awareness of how they and the standard of their work contribute to product quality. Equipment condition depends on their standard of work. Quality management efforts have made equipment condition important to controlling product quality (Swamidass 2002). 46% of employees remained neutral on the question on whether maintenance strategies adequately cover production equipment critical to product quality. This could indicate low awareness of which areas of the plant are critical to product quality or that maintenance strategies are treating these areas just like any other non-quality critical plant areas. Viewing this response in conjunction with the response to question 7 indicates the later might be more plausible. Because 74% of employees feel that spare parts are not always available for quality critical equipment indicates that they are aware of which plant areas are quality critical. On the other hand they may hold the view that spare parts are not always available for any part of the plant, be it quality critical or not.

The high positive response to questions 4 shows that maintenance employees are prepared to assist production staff in mitigating one of the 6 big losses, that is, setup and adjustments. This is also an indicator of a mature relationship between maintenance and production stuff even though 67% of employees see room for improvement in the standard of work and building a good working relationship with production stuff. The large standard deviation for this question is also an indicator of the low consensus within the team on this issue. Relationship maturity is a very important part of a successful quality management initiative. This is indicated by the response to question 5. Improvement of this cooperative spirit will ultimately improve product quality. The low standard deviation in the analysis of questions 5 and 6 show that there is department wide consensus supporting the importance of technical work standard and a good relationship between production and maintenance personnel.

Responses to question 8 indicate that employees feel that there is some level of promotion on quality as everyone's responsibility within the department. The team feels there is a lot of room for improvement as indicated by only 41% responses who agree that management emphasises the importance of maintenance to product quality, and only 7% strongly agreeing. In the powder plant in under study, maintenance strategies and personnel's involvement is critical to continuously improving and maintaining high quality.

## 5.3 RESEARCH IMPLICATIONS

The most significant observation from the results of this research was the degree of correlation between two seemingly unrelated production and maintenance variables. Similar studies have been done by researchers such as Tapiero, Rahim, Tagaras and Nguyen. In his research on continuous quality production and machine maintenance, Tapiero assumes quality to be a known function of the machine degradation state (Tapiero 1986). Rahim presented a model for jointly determining an economic production quantity, inspection schedule and control chart design for an imperfect production process (Rahim 1994). Tagaras considered a model that incorporates both process control and maintenance procedures to optimize their design parameters (Tagaras 1988). Nguyen used decrease in late deliveries and increased productivity to determine if maintenance scheduling can reduce unscheduled downtime (Hop 2011). Although further research is warranted using larger sampling and longer production periods, this research points to a possibility, at least in a milk powder factory setting, that there is a statistical dependence of product quality to maintenance activities as determined by maintenance strategies. As noted earlier due to time constraints and shortage of some records, the study was limited to one production cycle and one production plant. Further similar research in the dairy industry can be done using a number of powder plants and stretched over a 5 to 10 year period.

## 5.4 FURTHER RESEARCH

Findings from this research could be a basis for considering how changes within the maintenance regimes can be designed and implemented. Maintenance strategies that are quality focused could be designed by first looking at product quality requirements. Maintenance strategies have been designed with a focus on availability and machine reliability. By including a focus on quality on this list, not only will strategies consider maintenance execution but the standard of work and employee engagement as well.

# CHAPTER SIX: CONCLUSIONS

## 6.1 RESEARCH SUMMARY

This chapter summarises the overall research focusing on the research questions, their findings and the importance of the findings. It summarises research limitations and provides an insight into further research, as well as general comments from the researcher.

The purposed of the research was to find the relationship between the quality of milk powder and the maintenance management of the equipment used to manufacture the milk powder. Establishing this relationship would enable the drafting of maintenance management techniques that would focus on mitigating quality failures thus reducing the cost of quality failures. The study question was drilled down to three research questions, which when answered using findings from analysed data provides a comprehensive and clearer justification of the study hypothesis. SPSS statistical analysis was used to analyse the maintenance and production data gathered from the study factory for the 2011 to 2012 production period. Awareness of the maintenance team to their contribution to product quality was analysed using data from a survey that was carried out within the department. The data was analysed for mean, or point of convergence and consensus of responses to questions divided into technical, relationship with production and managerial support.

## 6.2 RESEARCH QUESTION 1 SUMMARY

### 6.2.1 Research Question

What are the quality attributes of powder milk that depend on effective equipment maintenance?

### 6.2.2 Findings Summary

Cost of quality failure was measured by summing the costs related to product downgrades, product on hold and customer complaints. Data was gathered from the factory for downgrades and customer complaints and statistically analysed with maintenance related data such as maintenance related unplanned stoppages, reactive maintenance and mean time between failures. There was a significant correlation between maintenance data, particularly unplanned plant stoppages and production data, such as product downgrade. These downgrades have been recorded as having being caused by quality attributes like sieve tests, wettability and low protein. Therefore the correlation results establish a relationship between quality attributes and equipment maintenance. Although there was no significant correlation between any maintenance data and customer complaints, some of the complaints were recorded as having been caused by equipment related issues.

## 6.3 Research Question 2 Summary

### 6.3.1 Research Question

Can powder milk quality issues be mitigated by changes in equipment maintenance strategies and implementation?

### 6.3.2 Findings Summary

Bivariate correlation analysis used to analyse production and maintenance variables shows a strong relationship between unplanned stoppages and product downgrades. This result and graphical data analysis show that periods were there were high levels of unplanned plant stoppages also experienced a high level of product downgrade, which would translate to high cost of quality failures. These quality issues can be mitigated by maintenance strategies and techniques that can effectively reduce the number of unplanned plant stoppages. Finding also show that preventive to reactive maintenance ratio is much lower than 20 to 80 ratio. Maintenance programs that aim to reverse this ratio may have a significant impact on the number of unplanned stoppages and thus mitigate the quality issues. This has the potential to play a part in the 60% reduction in cost of quality in Plant A during the 2012 to 2013 production season. Figure 16 shows that to get to the target of $3M, appraisal and prevention cost, like the implementation of the maintenance programs, may increase in the short term but decrease as the program takes effect and become business as usual. The entrenchment of TPM techniques, such as autonomous maintenance, will put less pressure on the maintenance team and reduce prevention cost.

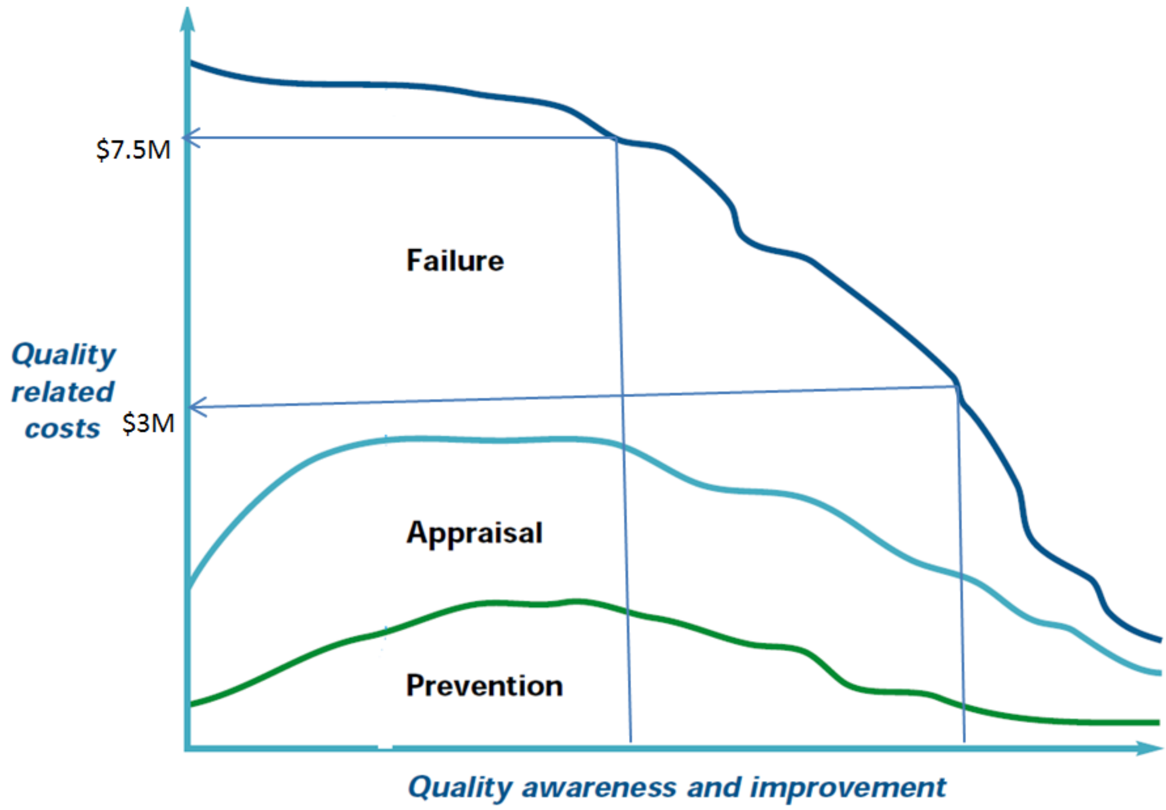



**Figure 16 - PAF Model – Low COQF can be achieved with lower appraisal and prevention cost.**

## 6.4 Research Question 3 Summary

### 6.4.1 Research Question

To what extent are maintenance strategies and personnel involved in continuously improving the quality of milk powder?

### 6.4.2 Findings Summary

The extent to which maintenance strategies and personnel can improve the quality of milk powder was investigated using a survey within the maintenance team. Findings show that there is a very high level of awareness of how the team's relationship with production personnel and the standards of their work can make a difference in product quality. On some of the questions, like those investigating co-operative spirit and standard of technical work, there was team wide consensus. While questions dealing with management's promotion of quality involvement by the department had a high standard deviation, indicating diversity of answers.

## 6.5 CONCLUDING REMARKS

Findings from the research show that there is significant relationship between the quality of milk powder and the way equipment that is used in the production process is maintained. There also show that the maintenance team has a significant contribution to make in the quality of the product. These finding will contribute towards designing strategies for mitigating cost of quality failures, particularly those strategies that are equipment focused. They are also important in contributing to the crafting of quality focused maintenance strategies.

As the study was limited to one production cycle and a single factory, further similar research using data spanning 5 to 10 years from multiple plants would help to strengthen the significance of these findings. It is evident that product quality and equipment maintenance are deeply interlinked. It is therefore imperative for any industry that wants to improve product quality to take a serious look at its maintenance programs and review how they can be formulated with a focus on product quality. This study is a small but significant contribution to the knowledge base that aims to finding solutions to quality issues in the manufacture of milk powder within the New Zealand dairy industry.

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# APPENDIX

## APPENDIX A – SURVEY INFORMED CONSENT FORM

| |
|---|
| **Study Title or Topic:** The quality of milk powder and its dependency on equipment maintenance Management |
| **Researcher's Full Name**: Ambrose T. Mpofu |
| **University:** Massey University |
| **Program:** Masters of Business Administration (MBA) |

**Purpose of the Research:** The purpose of this study is to contribute to the understanding of the relationship between equipment maintenance management and the quality of goods produced in a manufacturing environment. It is about the link between the machine factors and product quality in the New Zealand dairy industry in general and the manufacturing of milk powder in particular.

**Voluntary Participation**: Your participation in the study is completely voluntary and you may refuse to answer any question or choose to stop participating at any time. Your decision not to volunteer will not influence the nature of your relationship with the researcher or the University either now, or in the future. The document collection and surveys used are not intrusive and will not jeopardise the well-being, reputation or healthy and safety of the participants.

**Confidentiality**: All information you supply during the research will be held in confidence and, unless you specifically indicate your consent, your name will not appear in any report or publication of the research. Confidentiality will be provided to the fullest extent possible.

**Questions about the Research:** If you have questions about the research in general or about your role in the study, please feel free to contact:

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## Appendix B - Survey and Feedback from the Maintenance Team.

The purpose of this survey is to study the extent of awareness of the contribution of equipment maintenance to product quality within the maintenance team.

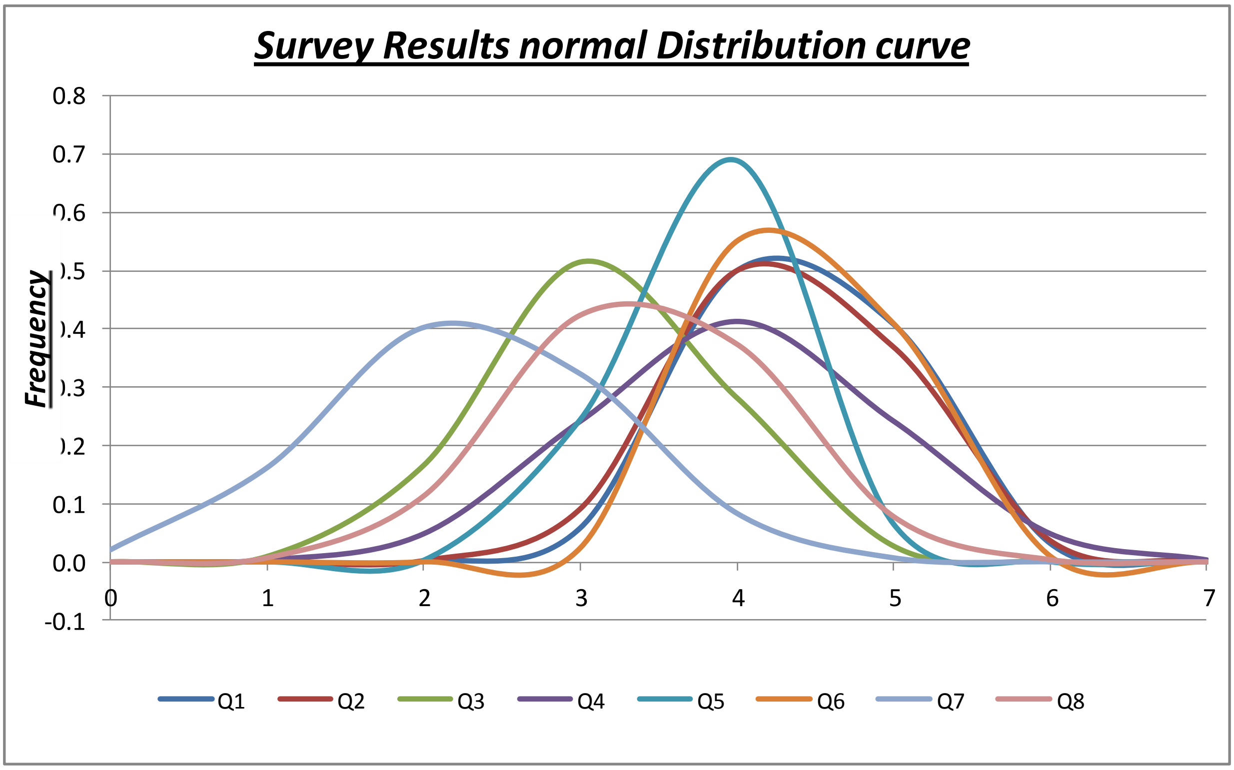
An informed consent form must be read and signed by each participant before taking part in this survey

| Please rate the following on a scale of 1-5. | | 1 if you strongly disagree and 5 if you strongly agree | | | | |
|---|---|---|---|---|---|---|
| **Scale** | | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| | | **1** | **2** | **3** | **4** | **5** |
| Q1 | The maintenance team has a contribution to make in product quality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q2 | The quality of equipment maintenance has an effect on product quality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q3 | Current maintenance regimes (Preventive, corrective maintenance. Etc.) adequately cover production area that directly affect product quality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q4 | The maintenance team has a role to play in the setup and tuning of equipment to achieve the best quality product. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q5 | The standard of maintenance both technical and customer relations can be improved so as to improve product quality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q6 | The co-operative spirit between the maintenance team and production teams has an effect on product quality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q7 | Spare parts that affect product quality are always available when needed. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Q8 | Company management emphasises the importance of maintenance to product quality. | ☐ | ☐ | ☐ | ☐ | ☐ |
| **Comments:** | | | | | | |

## Appendix C - Awareness Survey Results.

| | Question | Strongly Disagree | Disagree | Neutral | Agree | Strongly Disagree | Mean | Standard Deviation |
|---|---|---|---|---|---|---|---|---|
| **Q1** | *The maintenance team has a contribution to make in product quality* | 0 | 1 | 1 | 22 | 22 | 4.4 | 0.7 |
| | | 0% | 2% | 2% | 48% | 48% | | |
| **Q2** | *The quality of equipment maintenance has an effect on product quality* | 0 | 1 | 3 | 21 | 21 | 4.3 | 0.7 |
| | | 0% | 2% | 7% | 46% | 46% | | |
| **Q3** | *Current maintenance regimes (Preventive, corrective maintenance. etc.) adequately cover production area that directly affect product quality* | 1 | 7 | 20 | 16 | 0 | 3.2 | 0.8 |
| | | 2% | 15% | 43% | 35% | 0% | | |
| **Q4** | *The maintenance team has a role to play in the setup and tuning of equipment to achieve the best quality product.* | 1 | 3 | 6 | 21 | 15 | 4.0 | 1.0 |
| | | 2% | 7% | 13% | 46% | 33% | | |
| **Q5** | *The standard of maintenance both technical and customer relations can be improved so as to improve product quality* | 0 | 0 | 12 | 31 | 3 | 3.8 | 0.5 |
| | | 0% | 0% | 26% | 67% | 7% | | |
| **Q6** | *The co-operative spirit between the maintenance team and production teams has an effect on product quality* | 0 | 0 | 1 | 25 | 20 | 4.4 | 0.5 |
| | | 0% | 0% | 2% | 54% | 43% | | |
| **Q7** | *Spare parts that affect product quality are always available when needed.* | 7 | 23 | 11 | 2 | 2 | 2.3 | 0.9 |
| | | 15% | 50% | 24% | 4% | 4% | | |
| **Q8** | *Company management emphasises the importance of maintenance to product quality.* | 0 | 7 | 16 | 19 | 3 | 3.4 | 0.8 |
| | | 0% | 15% | 35% | 41% | 7% | | |

## Appendix D - Survey Results Normal Distribution




**Normal Distribution show diversity of answers per question**

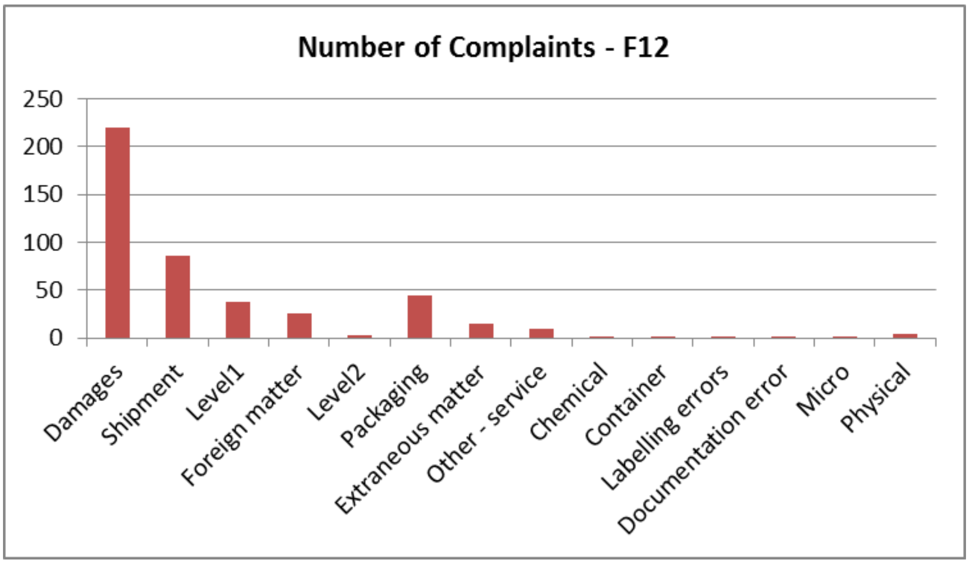
## APPENDIX F – EQUIPMENT RELATED PLANT SHUTDOWNS.

| F12 - Maintenance Related Plant Shut Downs | |
|---|---|
| **Fault Type** | **Number of Occurrences** |
| Milk Treatment breakdown | 4 |
| Misc. Evaporator mechanical fault | 3 |
| start up | 2 |
| Blocked Cyclone | 14 |
| Misc. Drier mechanical fault | 11 |
| Drier off product | 5 |
| Homogeniser electrical fault | 19 |
| Misc. Drier Fault | 7 |
| Motor mechanical fault | 1 |
| Loss of steam supply | 2 |
| Valve electrical fault | 2 |
| Misc. Drier electrical fault | 1 |
| FSOE7 divert | 9 |
| Powder transport PLC fault | 3 |
| Power cut | 18 |
| Valve mechanical fault | 1 |
| Homogeniser PLC fault | 2 |
| Waiting for Whole milk | 17 |
| Loss of water services | 6 |
| Homogeniser electrical fault | 19 |

## APPENDIX E – CAUSES OF CUSTOMER COMPLAINTS.

| Cause of Complaint | Number of Complaints |
|---|---|
| Damages | 220 |
| Shipment | 86 |
| Level1 | 38 |
| Foreign matter | 26 |
| Level2 | 3 |
| Packaging | 44 |
| Extraneous matter | 15 |
| Other - service | 9 |
| Chemical | 2 |
| Container | 1 |
| Labeling errors | 1 |
| Documentation error | 1 |
| Micro | 1 |
| Physical | 4 |

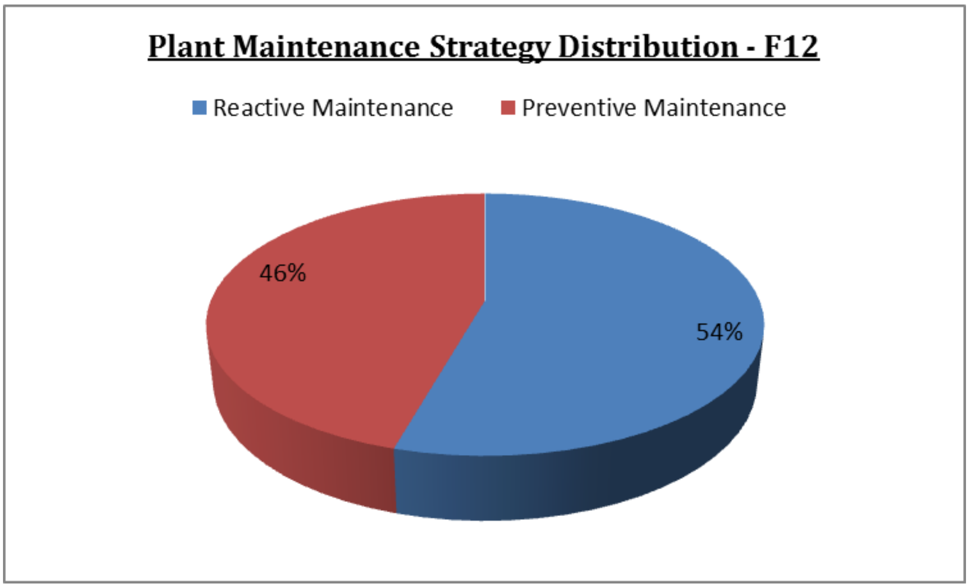
Causes of Customer complaints – graphical representation



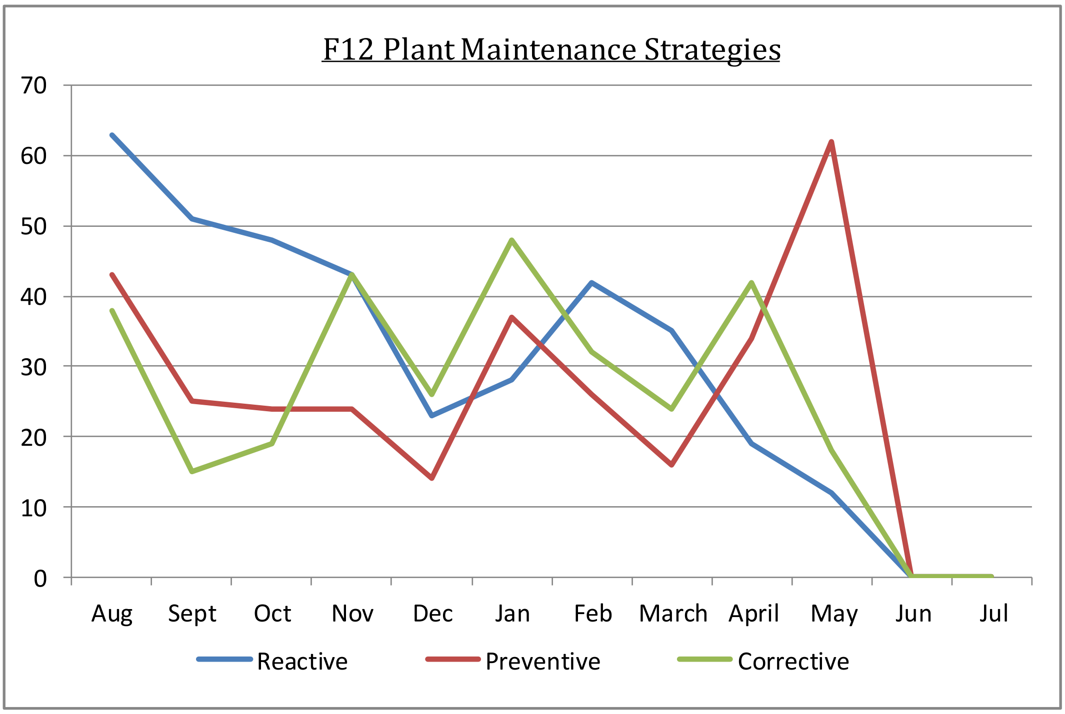

## APPENDIX G - PLANT MAINTENANCE STRATEGIES

| Month | Number Of Reactive Maintenance (RM) | Number Of Preventive Maintenance (PM) | Number Of Corrective Maintenance (CM) |
|---|---|---|---|
| Aug | 63 | 43 | 38 |
| Sept | 51 | 25 | 15 |
| Oct | 48 | 24 | 19 |
| Nov | 43 | 24 | 43 |
| Dec | 23 | 14 | 26 |
| Jan | 28 | 37 | 48 |
| Feb | 42 | 26 | 32 |
| March | 35 | 16 | 24 |
| April | 19 | 34 | 42 |
| May | 12 | 62 | 18 |
| Jun | 0 | 0 | 0 |
| Jul | 0 | 0 | 0 |
| **Total** | **364** | **305** | **305** |

Season Plant Maintenance activities

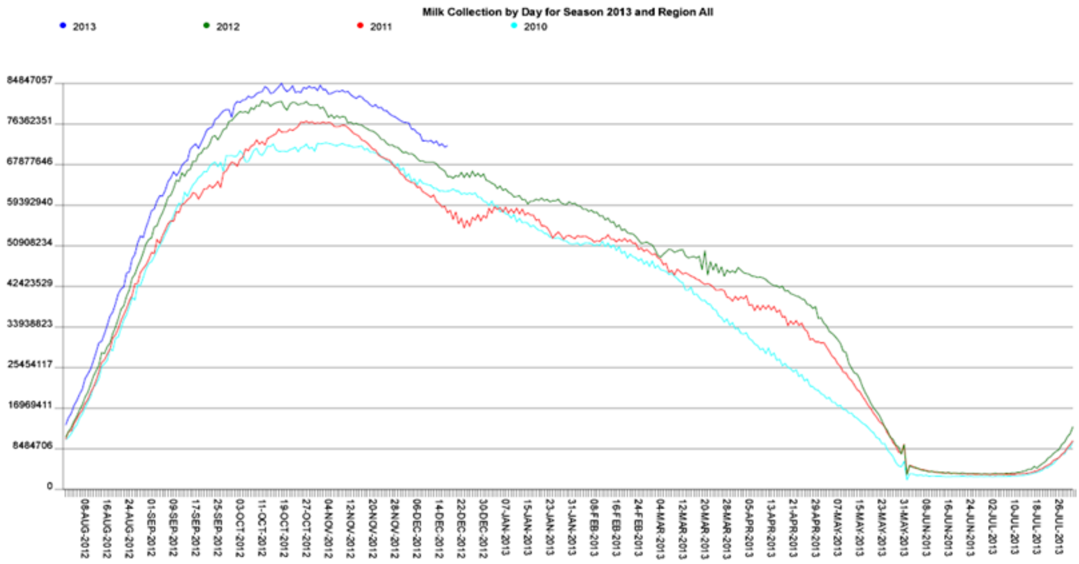



Season Plant Maintenance activities month by month



# APPENDIX H – SITE MILK VOLUMES PER SEASON.

| Milk Powder Total metric tons produced F12 | | | |
|---|---|---|---|
| Powder Plant | Manufactured (MT) | 1st Time Graded (MT) | % |
| | 130697.88 | 126,280.30 | 96.62 |




F12 2011 to 2012 Season in Red

# Appendix I – SPSS Correlation Analysis

**SPSS Correlations Analysis**

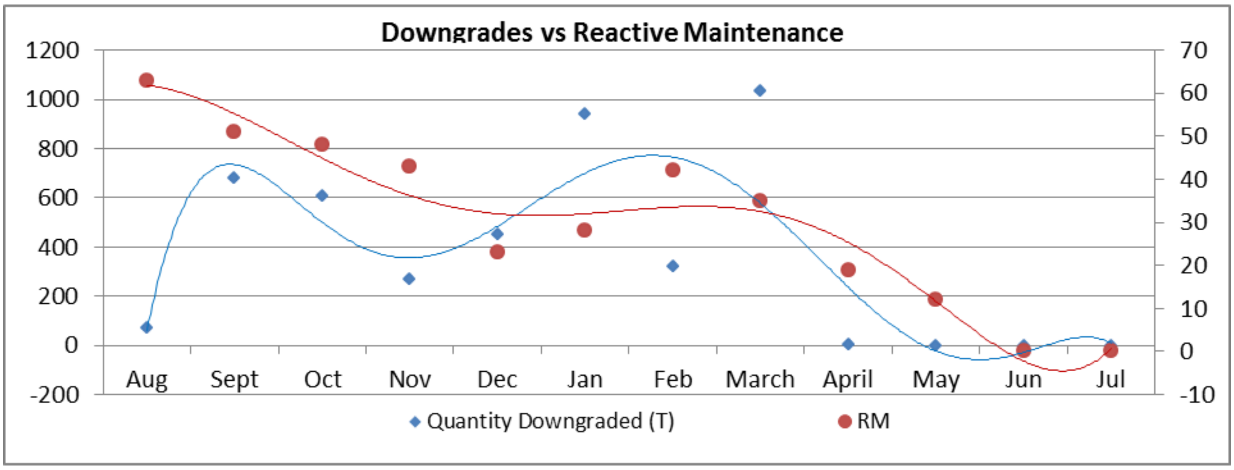
| | | All Unplanned Shuts | All Planned Shuts | Total Run (Hrs) | Maint Rel Unplanned Shuts (hrs) | Quantity Downgraded (T) | Quantity Manufactured (T) | Complaints ($) | MTBF (hrs) | RM | PM | CM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All Unplanned Shuts | Pearson Correlation | 1 | .426 | .540 | .671* | .510 | .372 | .339 | .620* | .606* | .394 | .227 |
| | Sig. (2-tailed) | | .168 | .070 | .017 | .090 | .234 | .281 | .032 | .037 | .205 | .477 |
| All Planned Shuts | Pearson Correlation | .426 | 1 | .886** | .673* | .554 | .915** | .156 | .407 | .683* | .285 | .608* |
| | Sig. (2-tailed) | .168 | | .000 | .016 | .061 | .000 | .628 | .189 | .014 | .369 | .036 |
| Total Run (Hrs) | Pearson Correlation | .540 | .886** | 1 | .599* | .474 | .864** | .221 | .444 | .709** | .649* | .763** |
| | Sig. (2-tailed) | .070 | .000 | | .039 | .119 | .000 | .490 | .149 | .010 | .022 | .004 |
| Maint Rel Unplanned Shuts (hrs) | Pearson Correlation | .671* | .673* | .599* | 1 | .845** | .749** | .363 | .295 | .429 | .028 | .267 |
| | Sig. (2-tailed) | .017 | .016 | .039 | | .001 | .005 | .246 | .352 | .164 | .931 | .402 |
| Quantity Downgraded (T) | Pearson Correlation | .510 | .554 | .474 | .845** | 1 | .661* | .380 | .333 | .398 | -.056 | .253 |
| | Sig. (2-tailed) | .090 | .061 | .119 | .001 | | .019 | .223 | .291 | .200 | .863 | .428 |
| Quantity Manufactured (T) | Pearson Correlation | .372 | .915** | .864** | .749** | .661* | 1 | .062 | .373 | .581* | .248 | .686* |
| | Sig. (2-tailed) | .234 | .000 | .000 | .005 | .019 | | .847 | .233 | .048 | .438 | .014 |
| Total Downgrades (T) | Pearson Correlation | .555 | .561 | .491 | .853** | .997** | .660* | .397 | .366 | .450 | -.037 | .264 |
| | Sig. (2-tailed) | .061 | .057 | .105 | .000 | .000 | .020 | .201 | .242 | .142 | .910 | .407 |
| Complaints ($) | Pearson Correlation | .339 | .156 | .221 | .363 | .380 | .062 | 1 | -.084 | .224 | .112 | .030 |
| | Sig. (2-tailed) | .281 | .628 | .490 | .246 | .223 | .847 | | .795 | .484 | .730 | .925 |
| MTBF (hrs) | Pearson Correlation | .620* | .407 | .444 | .295 | .333 | .373 | -.084 | 1 | .597* | .267 | .589* |
| | Sig. (2-tailed) | .032 | .189 | .149 | .352 | .291 | .233 | .795 | | .041 | .401 | .044 |
| RM | Pearson Correlation | .606* | .683* | .709** | .429 | .398 | .581* | .224 | .597* | 1 | .338 | .511 |
| | Sig. (2-tailed) | .037 | .014 | .010 | .164 | .200 | .048 | .484 | .041 | | .282 | .090 |
| PM | Pearson Correlation | .394 | .285 | .649* | .028 | -.056 | .248 | .112 | .267 | .338 | 1 | .536 |
| | Sig. (2-tailed) | .205 | .369 | .022 | .931 | .863 | .438 | .730 | .401 | .282 | | .073 |
| CM | Pearson Correlation | .227 | .608* | .763** | .267 | .253 | .686* | .030 | .589* | .511 | .536 | 1 |
| | Sig. (2-tailed) | .477 | .036 | .004 | .402 | .428 | .014 | .925 | .044 | .090 | .073 | |

**. Correlation is significant at the 0.01 level (2-tailed).

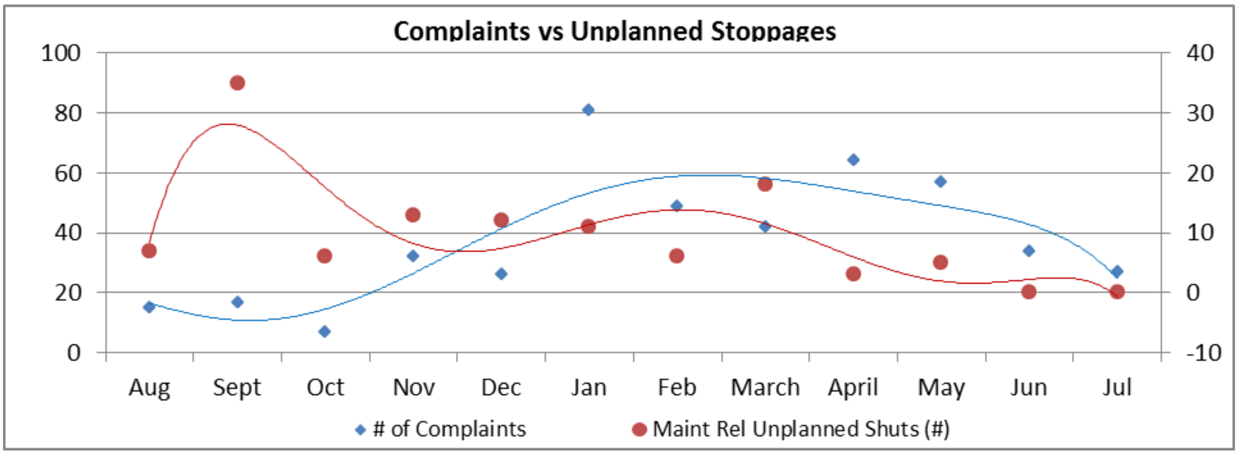
*. Correlation is significant at the 0.05 level (2-tailed).

# Appendix J – Maintenance vs. Production Scatter charts.

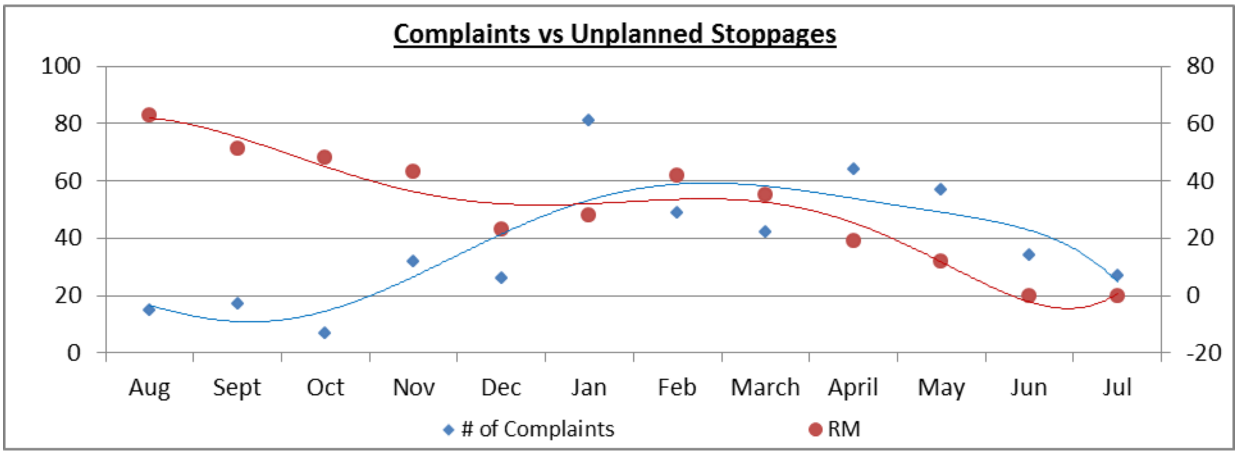
## Appendix J1




## Appendix J2




## Appendix J3



# APPENDIX K – LOW RISK NOTIFICATION APPROVAL

**MASSEY UNIVERSITY**
TE KUNENGA KI PŪREHUROA

19 November 2012

Ambrose Mpofu
153 Waihi Road
**HAWERA 4610**

Dear Ambrose

**Re: The Quality of Milk Powder and its Dependency on Equipment Maintenance Management**

Thank you for your Low Risk Notification which was received on 16 October 2012.

Your project has been recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis that it is safe to proceed without approval by one of the University's Human Ethics Committees.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

**A reminder to include the following statement on all public documents:**

> *"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.*
>
> *If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, e-mail humanethics@massey.ac.nz".*

Please note that if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to provide a full application to one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

J. O'Neill

John G O'Neill (Professor)
**Chair, Human Ethics Chairs' Committee and**
**Director (Research Ethics)**

cc Assoc Prof Nigel Grigg
School of Engineering and Advanced Technology
**PN321**

Prof Don Cleland, HoS
School of Engineering and Advanced Technology
**PN456**

Massey University Human Ethics Committee
Accredited by the Health Research Council

**Research Ethics Office**

Massey University, Private Bag 11222, Palmerston North 4442, New Zealand T +64 6 350 5573 +64 6 350 5575 F +64 6 350 5622
E humanethics@massey.ac.nz animalethics@massey.ac.nz gtc@massey.ac.nz **www.massey.ac.nz**

# APPENDIX L – COMPANY WRITTEN APPROVAL - CONFIDENTIALITY AGREEMENT

[redacted]

**CONFIDENTIALITY AGREEMENT**

**([redacted] Disclosing Confidential Information One-way)**

| | |
|---|---|
| FONTERRA | [redacted] Co-operative Group Limited<br>9 Princes Street<br>Auckland New Zealand |
| RECIPIENT | Massey University<br>Executive MBA. Private Bag 11 222, Palmerston North, 4442. New Zealand. |
| PURPOSE | Research study for the Masters of Business Administartion. (MBA) by Ambrose T Mpofu. Employee number 370152. |
| SPECIAL TERMS | |
| DATE | 12 November 2012 |

Fonterra has agreed to disclose certain information to the Recipient for the Purpose.

The Recipient:

- acknowledges that the information disclosed to it for the Purpose is Confidential Information;
- agrees that all intellectual property arising from the Purpose is the property of Fonterra; and
- agrees to be bound by the terms set out in this agreement and any schedule to it.

| | | |
|---|---|---|
| PARTIES | [redacted] (as defined above) | Massey University Executive MBA |
| SIGNATURE | | |
| NAME | [Enter the name of the [redacted] contract authority]<br>Brian Purser | **[Enter the name of the other party contact]**<br>(A/Prof) NIGEL GRIGG |
| DATE SIGNED | 27-11-2012 | 12-11-12 |
| POSITION | [Enter the position of the [redacted] authority]<br>Maintenance Manager<br>Whareroa. | **[Enter the position of the other party contact]**<br>ASSOCIATE PROFESSOR, SUPERVISOR |
| ADDRESS | [redacted] Authority address]<br>PO Box 444<br>HAWERA<br>Email Address: brian.purser@fonterra.com | [Other party contact address]<br>SEAT, PALMERSTON NORTH, MASSEY UNIVERSITY<br>Email Address:<br>N.Grigg@massey.ac.nz |