

Quality management system to improve conveyor system performance: Lethabo Power Station as case study

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Preface

A quality management system (QMS) qualifies an organisation to set its goals and objectives and provide satisfaction and consistency in terms of material, equipment and methods applied in its processes. A quality management system interacts with all activities in the organisation starting with identification of requirements and satisfying them at any operational interface. An effective QMS is a strategy to deliver business objectives and use a process approach to transform input to create output (product/service) of value for the organisation and its customers.

Like any industrial machine conveyor system, performance deteriorates with time. This also relates to equipment operation and maintenance including environmental conditions. This research investigates the root causes of conveyor failures focusing on technical, processes and system requirements.

Abstract

Eskom Lethabo Power Station experienced a number of ash plant conveyor failures that resulted in production loss and plant damages. This study was aimed at determining the root causes of the failures (technical, management system and process) that led to conveyor unreliability. The problem was verified by interviewing people working in the plant and by analysing financial, technical and process data.

A hypothesis was made that the problem emanates from poor quality management practices; this was confirmed by carrying out root cause analyses on 10 major events that occurred. It was evident that the costs of poor quality in the ash plant were very high and requires urgent attention.

A literature review was conducted to establish whether the quality management system complies with the requirements of ISO 9000 and total quality management (TQM). The survey found that the Eskom Lethabo Power Station partly complies with the requirements of ISO 9001 on an organisational level. However, the ash plant did not comply with the requirements of ISO 9000 in performing its daily duties.

The plant quality documents and systems were evaluated to establish whether they could have prevented the incidents from occurring. It was found that the documentation and data records were inadequate.

To determine the root causes of the technical quality problems, a brainstorming session was conducted using the nominal group technique to gather data as quickly as possible. The cause and effect analysis was designed to identify all potential causes of the problem. The Pareto analysis was used to prioritise the identified causes.

The three factorial experiments were designed to measure process parameters (speed, mass, operating hours). Data was recorded using supervisory control and data acquisition (SCADA). The data was analysed using three factorial calculations. Data was validated by performing analysis of variance (ANOVA) calculations.

The survey questionnaire (using the Likert scale) was designed to measure the level of adherence of the ash plant employees and management to the requirements of the ISO 9001 management system. The questionnaire measured the elements of the quality management system (QMS) requirements, its importance and its implementation at the ash plant. The pilot interview was conducted with five respondents who are part of the selected population, and the results suggested that managing supplier quality was a major contributor to quality problems

The interview output was used to determine changes proposed to the ash plant QMS. All ideas were verified by the senior engineer and validated by the plant engineering manager.

Keyword: Quality managements system (QMS), Quality management, Organizational performance, Continuous improvement. ISO 9000

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Abbreviations

Abbreviation	Explanation
IBI	Integrated business improvement
ISO	International Organisation for Standardisation
OEM	Original equipment manufacturer
QMS	Quality management system
QA	Quality assurance
QC	Quality control
QP	Quality plan
TQM	Total quality management
TOC	Theory of constraint
SAP	System Application Processes
SSC	Submersible scrapper conveyor
JPC	Japanese pipe conveyor
OHS Act	Occupational Health and Safety Act
PDCA	Plan-do-check-act
PLC	Programmable logic controller
SCADA	Supervisory control and data acquisition
P_SD	Population standard deviation

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Chapter 1: Introduction

1.1 Introduction

“In the middle of difficulty lies opportunity” - Albert Einstein

Goetsch and Davis (2013:5) argue that quality management is generally acknowledged as an approach to organisational management which brings about enhanced performance (operational, technical and financial). Oahland (2003:154) points out that over the past decades, organisations throughout the world have been antagonistically trailing quality management since there is a commonly held view that high quality products and services result in improved performance.

The lack of a definitive theory, which explains and substantiates the way in which the quality management practices or dimensions are related to bring about improved organisational performance, has resulted in claims and counter-claims by advocates and opponents of quality management as its ability to deliver returns, explains Taylor (2009:157). Dolan (2000:252) indicates that it is important for every organisation to identify quality management practices, which maximally contribute to organisational performance and how the quality management practices interact and influence each other to culminate in superior organisational performance.

Goetsch and Davis (2013:3) point out that the definitions of quality are mostly based on quality conformance to requirements, fitness for purpose, meeting customer perceptions, exceeding customer expectations and superior to competitor. Keller (2003:116) has identified performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality as critical dimensions of quality. Yusoff and Aspinwall (1999:141) explain that a quality management system (QMS) is a set of policies, processes and procedures required for planning and execution (production/development/service) in the core business area of an organisation (e.g. areas that can have an impact on the organisation's ability to meet customer requirements.)

Building and maintaining quality in an organisational infrastructure is a challenging task. In 1987, the International Organisation for Standardisation (ISO) developed a set of quality standards known as the ISO 9000 family as a model for QA and quality management for organisations involved in design, development, production, installation and services. ISO often reviews and updates the ISO 9000 standards to maintain their relevance to business needs and expectations (Goetsch & Davis, 2013:235). Total quality management (TQM) is a business

approach that maximizes organisational competitiveness through continual improvements of processes, environments, people, services and products.

1.2 Problem background

Coal is burnt in the boiler to supply heat which is necessary to generate steam. During this process ash is released from the boiler into the boiler ash hopper, while other materials are taken up by the flue gases and released in the gas passage as fly ash. The ash-handling plant continuously removes ash from the Eskom Lethabo Power Station in the form of both fly ash and coarse ash. The coarse ash is removed from the bottom of the boiler by the submerged scraper conveyor (SSC) and conveyed to the transverse conveyor via the Japanese pipe conveyor (JPC).

The fly ash is transported from precipitator hoppers by a hopper chain conveyor, through transfer conveyors to a bucket conveyor, moving ash to the fly ash bunker. The ash conditioning plant mixes dry fly ash from a fly ash bunker with water so that the resulting product can be handled mechanically without dust escaping to the atmosphere. The fly ash and coarse ash is transported by the same transverse conveyors onto the overland conveyors to the stacker via the extendable and shift-able conveyors. The ash stacker machine stacks the ash in the ash dump.

During normal operation, precipitator hoppers are to be kept empty at all times. This is necessary to prevent ash build-ups and cementing of ash in the hoppers when the ash temperature drops. During emergencies only, when the ash handling plant is unavailable or the fly ash bunker is full, fly ash can be stored for up to six hours in the precipitator hoppers. The submerged scraper conveyor (SSC) was designed to stop for one hour maximum at full load and load reduction to half load required after stopping more than an hour.

The other option is to dump ash in the emergency offloading area next to the station, which becomes a very costly exercise because trucks must be hired to remove ash in the emergency area or a front-end loader to reload the ash back on the conveyor system through an in-loading conveyor system. Figure 1 below shows the power plant process flow.

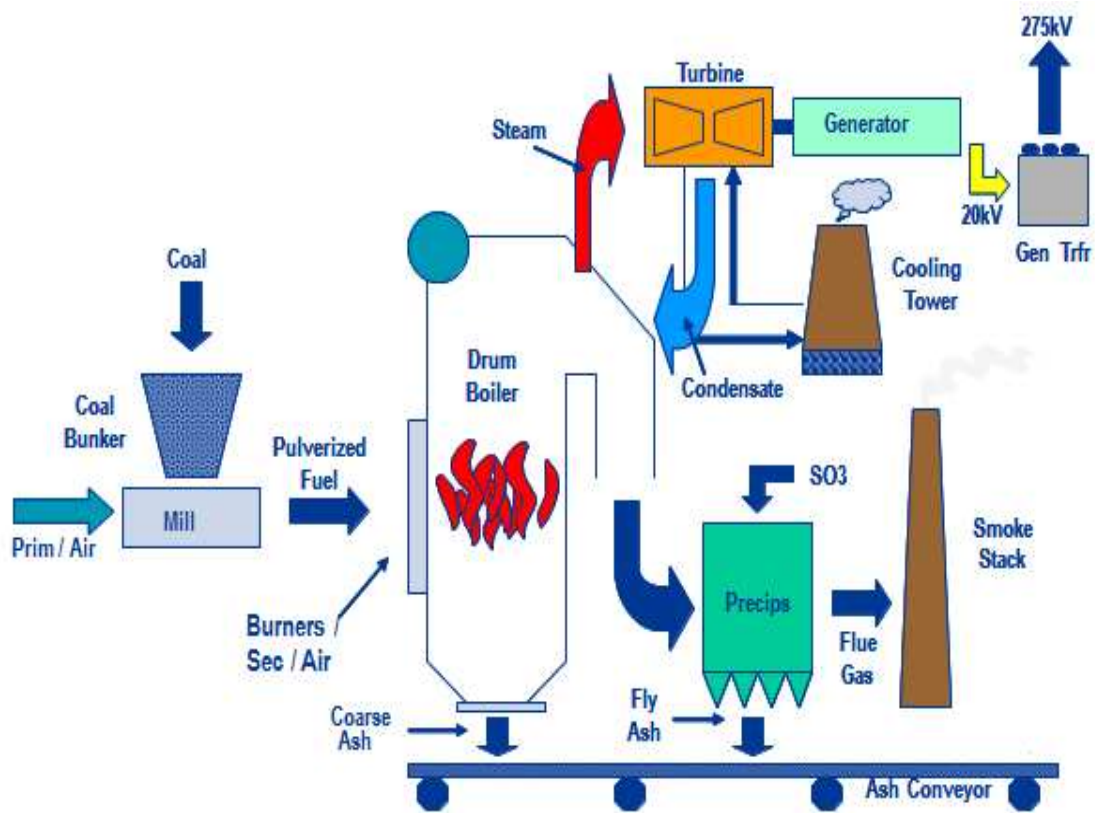


Figure 1: Power plant process flow

The Lethabo boilers are designed to use ash with a calorific value of 15 Mj/kg with ash content between 34 – 45%. The Vaal mine sometimes supplies bad batches with a caloric value of 13 Mj/kg and 38 – 50% ash content, which also increase ash production produced by the boiler per hour. The common ash line has a designed maximum capacity to transport 2 060 tons per hour to the ash stackers for emergency off-loading. The JPC has a design capacity to transport 32 tons an hour (coarse ash) and the conditioners (fly ash) 650 tons per hour. The total for six units is 192 tons per hour coarse ash, 1 950 tons per hour conditioned fly ash with a common ash system design capacity of 2 060 tons per hour. The major ash-related material handling innovations introduced at Lethabo power station was that the boilers were designed to use low to very low grade coal (low grade coal is supplied by the new Vaal Colliery) leading to large quantities of ash, between 16 000 and 20 000 tons per day, which required reliable, cost effective disposal.

1.3 Problem statement

The operating philosophy of the boiler requires that ash is continuously removed to prevent formation of ash clickers inside the boiler and the boiler ash-removal process protection requires that the unit reduces load to half load if the fly ash bunker level is above 90% or if the submersible scrapper conveyor (SSC) is out of operation for more than an hour. The continuous removal of both coarse ash (removed from the bottom of the boiler) and fly ash (removed by gases to the fly ash bunker on the upper part of the boiler) is equally important. Lethabo Power Station is an ISO 9001 certified organisation and external audits are conducted by certification bodies annually.

The problem was conveyor system failure resulting in an ash backlog in the boiler, precipitator hoppers, fly ash bunkers and the emergency off-loading area. The incapability of the ash plant conveyor system to meet or exceed its design performance requirements of continuously removing ash from the power station poses a significant risk to the boiler-operating licence, water-use licence and emissions licence (all power station statutory requirements).

The boiler-use licence restricts a boiler from running on full load if no ash is removed for more than half an hour or shut down after running more than an hour. The water-use licence requires that the emergency off-loading must be used minimally and that all water used during the ash cooling process must be recovered to prevent contravention of environmental regulations, as this may cause ash to contaminate water flow to the nearby Vaal River. The emissions licence requires that the power-generating unit must not operate with the fly ash system out of service because stack emissions go above the operating limit (Daily average of 100 milligram per cubic meter)

1.4 Research questions

The following were the research questions

1. What are the root causes (technical, process, system) of conveyor system failures in the ash plant?
2. Which elements of a QMS are satisfactory or not satisfactory, and to what extent?
3. What are the major factors/dimensions influencing performance in the ash plant?
4. What are the perceived benefits of implementing QMS?
5. What process parameters are important to ash-plant performance and how much variability do they have?

1.5 Aim of the study

The overall aim was to develop an integrated QMS (ISO 9000 and elements of TQM) that will be used to improve conveyor performance by measuring, controlling and managing output of critical processes involved to deliver results, ensuring that the conveyor system continuously meets or exceeds its performance requirements. This will be achieved by analysing current operational performance in comparison with the requirement of ISO 9001 and TQM to identify gaps.

1.6 Research objectives

This study was designed to investigate the root causes of conveyor failure in the ash plant with particular emphasis on the management system (principles of ISO 9000, Plan-Do-Check-Act (PDCA) operating principle and the key elements of total quality) in the current plant operating context. The objective of this research was to:

1. Identify the gaps between management systems in the ash plant compared to the requirements of ISO 9000 and TQM.
2. Analyse the process parameters to verify if the plant is operating within the design requirements and that it is capable to delivered desired results.
3. Investigate how quality processes can be used to ensure continuous improvement of ash plant performance.
4. Integrate quality processes to ensure all functions performed meet the needs for which they carried out.
5. Ensure quality is built into all sub-processes so that preventative and corrective actions can be applied timely when necessary.

1.7 Expected benefits

The following benefits will be achieved through the developed integrated quality management system:

1. Improve ash-plant performance – identifying all parameters that are important for managing performance.

2. Improve customer satisfaction – ensure that all customer expectations are met
3. Improve compliance - ensure that the ash plant complies to relevant standards, requirements and regulations
4. Develop a quality culture – ensure that goals and priorities are clearly established, communicated, and aligned with operational activities
5. Improve documentation management – document provided to manage processes, recorded and available when needed.

1.8 Significance of the study

This study will contribute in several ways:

1. First, knowledge gained from this study will be valuable to Eskom in general, but also specifically to Lethabo Power Station
2. Secondly, It will be of great help to sections, business units, and divisions within Eskom that are planning to implement QMS effectively, because it can serve as a guideline methodology for management of sections, business units, and divisions within Eskom to effectively plan and apply the requirements of the QMS standards based on results extracted from Eskom's Lethabo Ash Plant that share common factors and a similar culture.
3. Thirdly, the results of this research can benefit the quality practitioners and help them understand the roles they should play during the various stages of QMS implementation.
4. Lastly, this study will extend the boundaries of quality management literature.

1.9 Chapter overview

This dissertation contains six chapters, which were structured as follows:

Chapter 1: Introduction

Chapter 1 introduces the reader to the background of the research problem. It also discusses the significance of the study, the aims and objective of the study, the research question, the problem statement and the format of the entire study.

Chapter 2: Literature Review

Chapter 2 presents a thorough review of the relevant literature on quality control (QC) and quality management processes that can be used to develop a QMS. It also looks at the views of other authors who studied the topic of QMSs to determine how their arguments relate to this research.

This chapter also evaluates integration of quality management to all management activities ensuring objective decision making (decisions based on facts rather than opinions). The statistical method of analysing the data and experimental design is also discussed in this chapter.

Chapter 3: Experimental design

This chapter presents the experimental design of the ash process and the sequence according to which the experiment was conducted, as well as the way in which data was collected and delineated. The structure of the chapter includes the establishment of the research population, the process of investigation, the format of analysing the data received, the administration and development of the research instruments and how the data collected was analysed and presented. The chapter also looked at how information was verified and validated by comparing conclusion to similar research carried out in the past.

Chapter 4: Results

Chapter 4 presents the research results from an experiment performed in Chapter 3. A Pareto chart was used to record and interpret data from the Pareto analysis. A Survey questionnaire was used to investigate the eight elements of QMS importance and degree of application. Three factorial calculations were performed to determine if the process was within statistical control, and that it would deliver the desired results in its current context. The analysis of variance (ANOVA) calculations were also performed to verify and validate the experiment results.

Chapter 5: Discussion and interpretation

Chapter 5 presents the results, findings and interpretations utilising relevant theory presented in Chapter 2 to evaluate and analyse the relationship to generate new knowledge that can be used to elevate or resolve the problem.

Chapter 6: Conclusions and recommendations

Chapter 6 presents the conclusions and recommendations of the findings as presented in the previous chapters; it draws conclusions and discusses the implication of the study and finally provides suggestions for further study in the area of developing a QMS.

Chapter 2: Literature Review

This chapter reviews QMS theory designed to achieve two objectives. The first objective is to develop and articulate a theoretical model of quality management accomplished through a detailed analysis and interpretation of the published literature. The second objective of this study is to empirically test the plausibility of the proposed theory of quality management accomplished by fitting the model to the data gathered from the research process.

2.1 What is quality?

According to Goetsch and Davis (2013:247), the concept of quality can be viewed from different perspectives. For example, using the definition of quality being “free of deficiencies” requires the measurement of a number of defects; quality defined as “satisfying the customer” requires a determination of the number of satisfied customers; while defined as “conformance to specifications” requires measurement of conformance and or non-conformance.

Quality has evolved from inspection through QC and quality assurance (QA), to a system-based approach like TQM. The quality evolution has transformed organisations from inefficiency relying on inspections, autocratic leadership and hierarchical control, to a system of teamwork, paying attention to customer needs and satisfaction, getting quality right the first time, and continuously improving processes.

In the 21st century, organisations are forced to change old strategies and management styles, and develop better ways of allocating limited resources to remain competitive. Studies conducted by the Strategic Planning Institute (USA) found that there product/service quality is a major determinant of business productivity.

Deming points out that quality has a sequence reaction of positive results: "Improving quality leads to costs decrease with less rework and fewer delays which improves productivity and captures the market with better quality and lower prices". QMS is shown through policies, procedures, processes, resources and organisational structure required to implement quality management.

Early systems used simple statistics and random sampling to emphasize predictable outcomes of the products' production lines. According to Goetsch and Davis (2013:302), QMSs also focused on sustainability and the belief that quality problems would be reduced through documentation, systemic thinking and transparency. The two requirements of a QMS are customer requirement (ability of the organisation to deliver the desired products and services

consistently) and organisational requirements (optimum use of available resources both externally and internally), Taylor (2009:157).

2.2 What are the common types of quality problems?

Smith (2000:44) indicates that interpreting or responding to situations, well-founded problem types or categories must be used as an assurance of expert problem solving. Problem types or categories help direct attention to relevant past experiences and pertinent problem solving techniques. Three types of quality problems were differentiated by recognising the need to fit a problem solving response to the nature of the situation:

- Repair - to restore a malfunctioning system to its intended level of performance.
- Improve - to improve a system to achieve performance goals.
- Engineer - to design a new system or solution that will satisfy pertinent goals

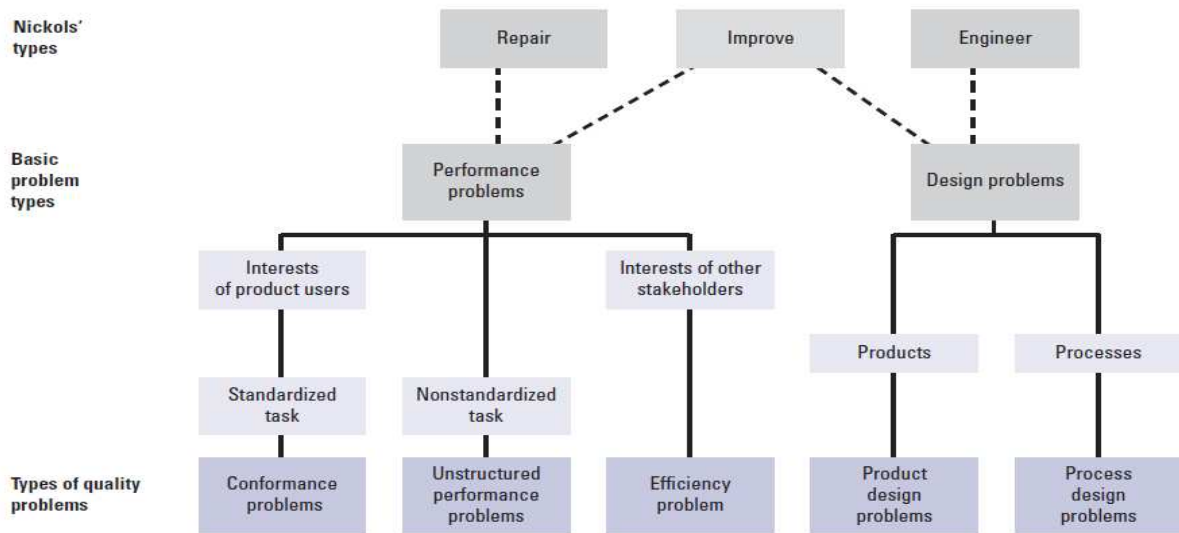


Figure 2: Types of quality problems (Smith, 2000)

2.3 Quality management

2.3.1 Introduction

Goetsch and Davis (2013:247) state that over the last thirty years, many studies have discussed the reasons for inferior quality in industries and have recommended quality improvement prescriptions in the form of quality management practice. Youssef, Koch and Dolan (2000:252)

define quality management practices as those quality techniques and behaviours entrenched within an organisation or its sub-units under two conditions:

- Techniques and behaviour are congruent with criteria established by the International Organization for Standardization (ISO) or they are embodied in a framework of national or international quality award frameworks
- Techniques must help organisations or its sub-units to achieve a sustainable competitive advantage at both operational and strategic levels so that they have an impact on the business performance of an organisation or one or more of its sub-units.

Quality aspects may be grouped into three broader fields which are quality of outputs, quality to satisfy customers and organization operational quality as shown in the Figure 3 below.

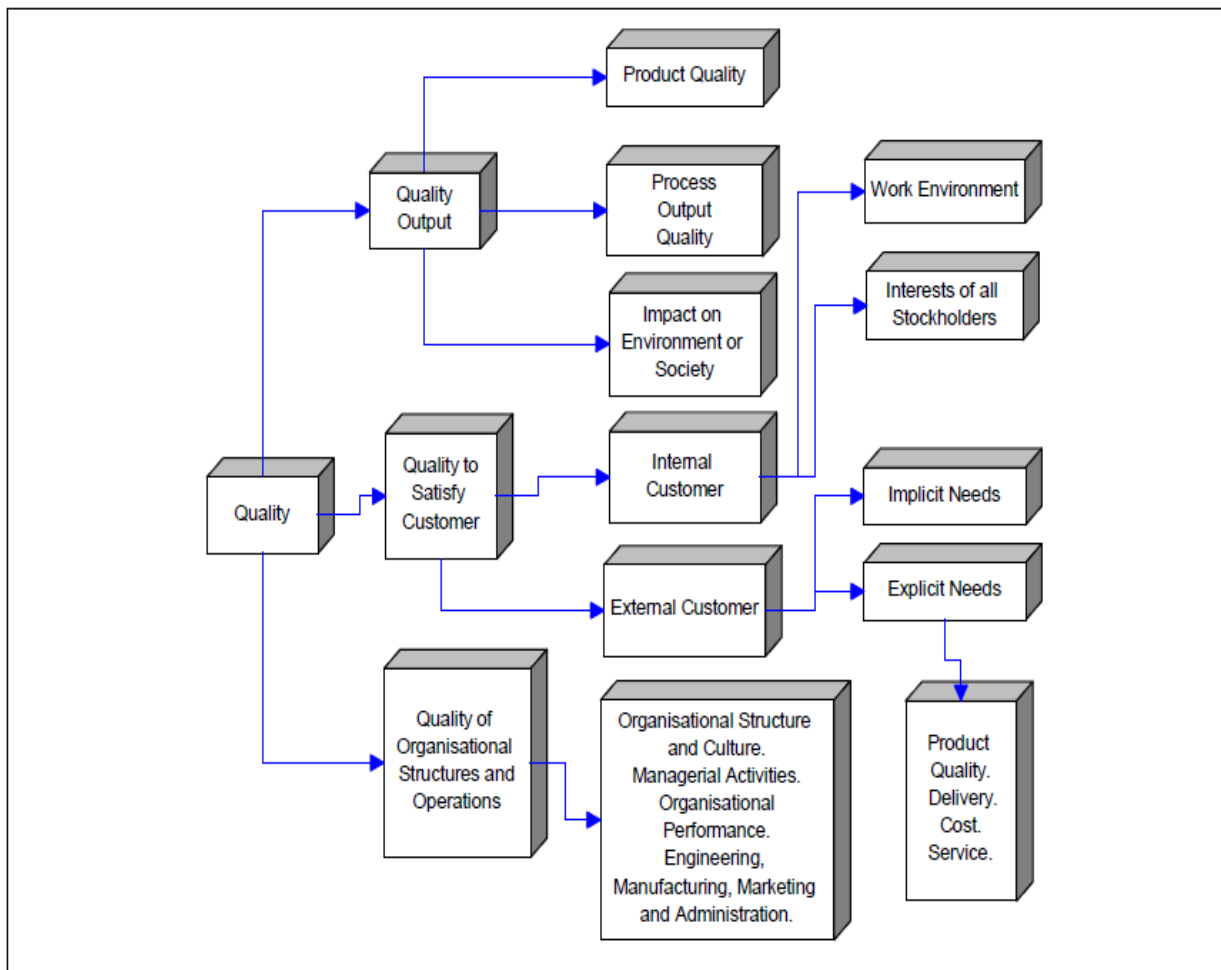


Figure 3: Comprehensive approaches to quality management (Keller, 2003:215)

2.3.2 Quality and performance

Keller (2003:215) argues that quality improvement is the use of a deliberate and defined improvement process and the continuous ongoing effort to achieve measurable improvements in performance. Performance management uses data for decision-making, by setting objectives, measuring and reporting progress toward those objectives, and engaging in quality-improvement activities when desired progress toward those objectives is not being made. Figure 4 below show factors that constitute quality management.



Figure 4: Factors that constitute quality management (Evans and Lindsay, 2014)

2.3.3 Deming's 14 points

Quality management is a philosophy of continuous organisational success through customer satisfaction, based on participation of all employees in continuously improving processes, services, and products. It is also evident that willingness and the ability to change and to improve, based on innovation lessons learned and benchmarking, are necessary components within the quality management approach. Deming classifies 14 points summarising and operationalising his philosophy (Known as Deming 14 points). Goetsch and Davis (2013:12)

2.3.4 Quality management practices at Eskom's Lethabo Power Station

The QMS documentation established for Eskom's Lethabo business is continually reviewed to ensure that it remains appropriate for the complexity and interaction of processes and the competence of all employees. The Lethabo quality manual (LBQIOOOO) prescribes how quality is embedded into organisational business as shown in figure 5 below.

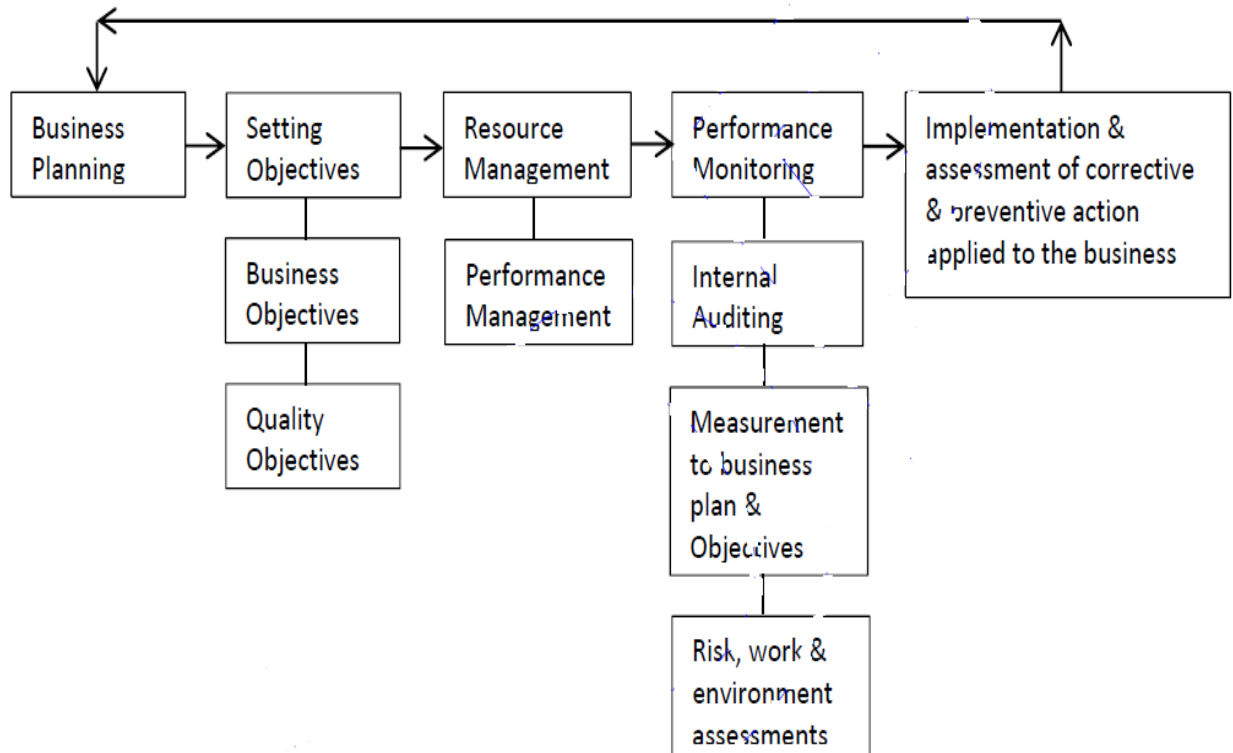


Figure 5: General quality management processes at Lethabo Power Station (LBQIOOOO-Lethabo quality manual)

2.3.5 Evolution of quality management

Goetsch and Davis (2013:38) point out that quality management can provide a clearly defined structural framework in which all organisational activity occurs. Employees must be empowered through self-directed or cross-functional workplace teams, multi-skilled flexible workforces, or dynamic workplace environments to ensure that they contribute maximally to organisational performance. Table 1 below shows five major phases of quality evolution

Table 1: Phases of quality evolution

Identifying characteristics	Inspection	Statistical quality control	Quality assurance	Strategic quality management	Competitive continuous improvement
Scope	Product quality	Process quality	Total quality		Excellent-sustainable organisation
Action	Reactive to quality problems		Proactive or preventing quality failure		Flexible, responsive, adapt quickly to changes
Focus	Conformance to specifications	Conformance to Customer	Total customer satisfaction	Customer comes first	Continuously add value to organisation's stakeholders
Orientation	Inspect quality	Control quality	Build in quality	Manage quality	
Methods and concepts	Gauging and measurement	Statistics: SPC sampling plan	Management practice	Integrating management practice	
Measure	Finished goods	In-process measurement	Entire production chain	Quality management system	Stakeholder satisfaction
Primary concern	Inspection	Detection	Coordination	Strategic impact	Continuous improvement
Quality target in production	No standard			Zero defect	
Key responsibilities	Inspector	Quality department	Active involvement of entire organisation		
Operating philosophy	Craftsman to mass production	Mass customisation	Flexible specialisation		

2.4 Total quality management (TQM)

2.4.1 What is total quality?

According to Goetsch and Davis (2013:18), total quality is an approach to doing business that attempts to maximise the competitiveness of an organisation through the continual improvement of the quality of its products, services, people, processes and environment. The total quality approach targets everything that affects quality for continuous improvement. The end results of

effective application of total quality include superior value, global competitiveness and organisational excellence focusing on:

- Measurements – this approach believes that how we measure determines the actions to be taken.
- People – empowering employees drives business performance.
- Processes – continuous improvements of process directly yield product or service improvement.

The Deming cycle is used as a continuous improvement tool that focuses on customer needs and on organisational resources for cooperative efforts to meet those needs, according to Goetsch and Davis (2013:11).

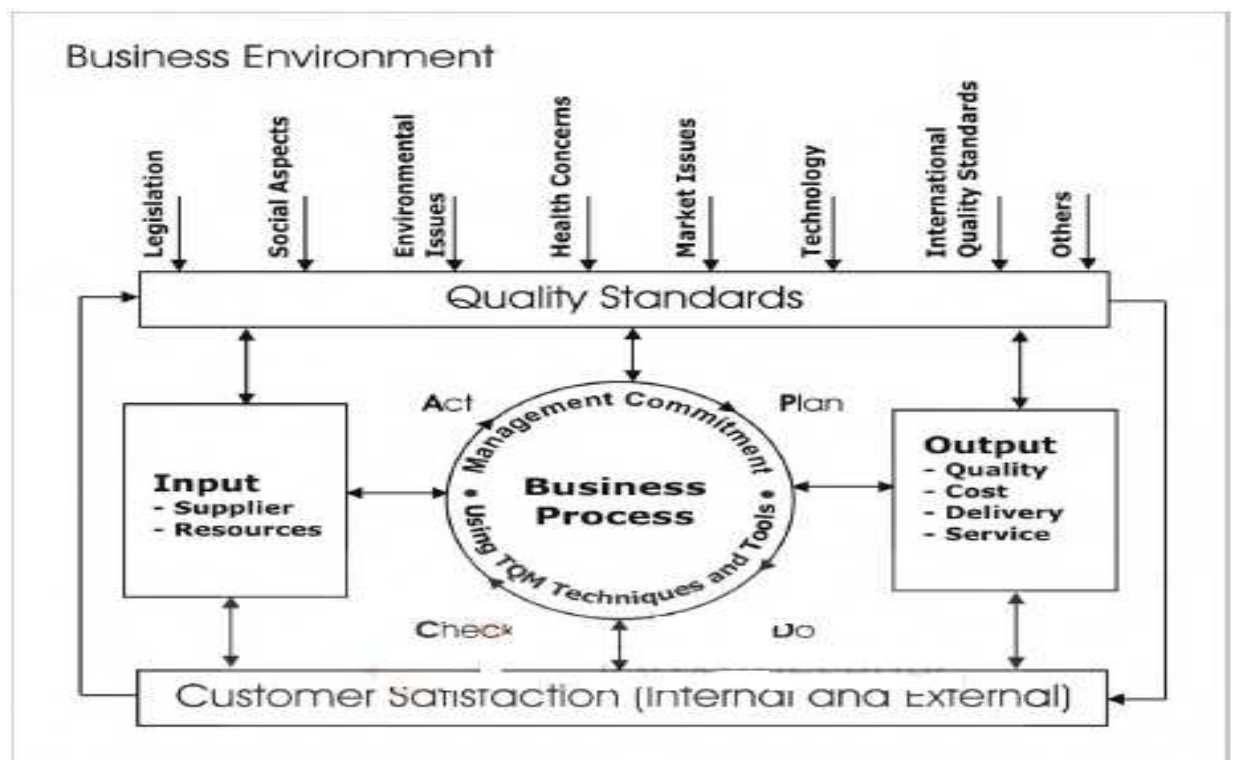


Figure 6: An integrated TQM system model (Goetsch & Davis, 2013)

2.4.2 How is total quality different?

Total quality is different from the traditional ways of doing business, and it can be found on how is accomplished. The three-legged stool of total quality are measurements (statistical process control, people (quality is built in, quality is expected not inspected, employees are empowered) and processes (continual improvement). Goetsch and Davis (2013:25)

2.4.3 How is total quality achieved?

The total quality approach has the following characteristics: Customer focus (Internal and external), obsession with quality, use scientific approach to decision making, teamwork, continual process improvement (people, processes, products, services and environment), education and training , freedom through control, unity of purpose, employee involvement and peak performance as a top priority. Goetsch and Davis (2013:289)

2.4.4 TQM implementation process

The 20-step TQM implementation processes shown in Table 2 below, provides a framework for any organisation, with only a little adjustment here and there to accommodate organisation-specific requirements understanding that no two TQM implementations will be exactly the same. The three phases of the implementation model are preparation, planning and execution. Goetsch and Davis (2013:21)

Table 2: TQM implementation process (Goetsch and Davis (2013))

Phase	Action by	Steps
Preparation	Top executive	1. Commitment to total quality
		2. Form total quality steering committee
	Consultation	3. Team building
		4. Total quality training for the steering committee
		Total quality steering committee
	Steering committee augmented	5. Create vision , guiding principle
		6. Set broad strategic objectives
		7. Communicate and publicise
		8. Identify organisation strength and weaknesses
9. Identify advocates and resistors		
Planning		Steering committee
	11. Baseline customer satisfaction	
	12. Plan implementation approach (Plan, do check , act)	
	13. Identify projects	
	14. Establish team composition	
Execution	Project teams	15. Provide team training
		16. Team activation and direction
		17. Team feedback loop with steering committee
		18. Customer satisfaction feedback loop
		19. Employee satisfaction feedback loop
	Steering committee	20. Modify infrastructure as necessary

2.5 What is ISO 9000

2.5.1 International standard for quality management

According to Goetsch and Davis (2013:21), ISO 9000 is a family of standards and guidelines related to QMS which sets requirement for assurance of quality and management involvement. ISO 9001 was the most comprehensive, covering research, design, development, production, shipping, and installation. The standards provided companies with a series of guidelines on how to establish systems for managing quality products and services. Registration for any of the ISO 9000 models requires establishing four levels of documentation:

1. Quality manual - describes the policy and responsibility of the organisation
2. Quality procedures - describes provides processes to the organisation
3. Work instructions - constitute anything required to do work correctly (e.g. drawings, specifications, chart, sheets)

4. Quality records - if the system is well designed and works well, it will produce information that will allow progress/trends to be measured.

The new ISO 9000 standards have a completely new structure based on the principles of TQM and consist of four parts.

1. ISO 9000: Quality management systems - fundamentals and vocabulary
2. ISO 9001: Quality management systems - requirements
3. ISO 9004: Quality management systems - guidance for performance improvement
4. ISO 19011: Guidelines on quality and environmental auditing

2.5.2 Principles of ISO 9000

ISO classified, principles which guarantee successful implementation of quality management QMS into eight quality management principles:

1. Customer focus – organisations depend on their customers and therefore should understand current and future customer needs, meet customer requirements, and strive to exceed customer expectations.
2. The leadership - leaders establish unity of purpose and the direction of the organisation. They should create and maintain an internal environment in which employees can become fully involved in achieving the organisation's objectives.
3. Involvement of people - people at all levels are the essence of an organisation, and their full involvement enables their abilities to be utilised for the organisation's benefit.
4. Process approach - a desired result is achieved more efficiently when activities and related resources are managed as a process.
5. Systems approach to management - identifying, understanding and managing interrelated processes as a system contributes to the organisation's effectiveness and efficiency in achieving its objectives
6. Continual improvement - continual improvement of the organisation's overall performance should be a permanent objective of the organisation.
7. Factual approach to decision making - effective decisions are based on analysis of data and information

8. Mutually beneficial supplier relationships - an organisation and its suppliers are interdependent, and a mutually beneficial relationship enhances the ability of both to create value.

Goetsch and Davis (2013:21)

2.5.3 Continuous improvement

The plan-do-check-act (PDCA) circle is considered an operating principle of the ISO management system used for continuous improvement of products, services, processes and a system of processes. The steps are:

1. Plan - objectives must be established and achievement plan put in place
2. Do - implement the plan
3. Check - measure action results and determine if it satisfy the objective
4. Act - make adjustment to the plan and go back to step one.

2.6 ISO 9000 and total quality management (TQM)

2.6.1 Comparison ISO 9000 and total quality management (TQM)

The two main quality initiatives in the world today is ISO 9000 and total quality management. It is important to understand the similarities and differences between the two. The following statement outlines the relationship:

1. ISO 9000 is compatible with and can be viewed as a subset of TQM- TQM and ISO 9000 are not the same thing. TQM embraces all characteristics of ISO 9000, but ISO 9000 is not obsessed with quality, partially long-term committed, partially employees' involvement as TQM does.
2. ISO 9000 and TQM are related not interchangeable – by definition, ISO is concerned only with management systems for design, development, purchasing, production, installation and servicing of products and services. Total quality encompasses every aspect of the business including systems, processes and all support systems (human resources, finance and marketing) and involves every function and level of the organisation from top to bottom.

3. ISO 9000 is frequently implemented in a non TQM environment – TQM is not a prerequisite of ISO 9000 implementation. Most ISO 9000 registered organisations are not compliant to TQM requirements.
4. ISO 9000 can improve operations in a traditional environment – when ISO 9000 is implemented in an organisation, it should be better for it. This means that if the commitment from top management is not there, the system will end up being a marketing tool, while the organisation's functional department might develop even more problems than they had before ISO 9000.
5. ISO 9000 can be redundant in a mature TQM – all ISO 9000 requirements should be achieved in a mature TQM environment (above 600 on a scale of 1000 points). Registration with ISO 9000 can only assist for marketing if the company products are not yet considered world class.
6. ISO 9000 and TQM are not in competition – organisations can adopt either TQM or ISO 9000, or both because the two concepts fit well with each other and have similar aims.

2.6.2 ISO 9000 and TQM working together

Organisations that have adopted TQM can find themselves seeking ISO 9000 registration, since there is currently no international certification of TQM although ISO 9000 requirements are already achieved as a way to satisfy its customer. Traditional organisations registered under ISO 9001 may like TQM implementation to stay competitive. The two systems are compatible with each other and ISO 9000 is seen as already included in TQM.

2.6.3 ISO 9000 as an entry for TQM

Organisations always find it difficult to begin their total quality journey. To start a journey of ISO 9001 registration can be a good strategy because this can be viewed as an entry project for implementing TQM. For organisations attempting to adopt total quality and also benefit from ISO 9000, integrating the implementation steps should be considered. With this approach, the organisation should know that for example, after step 12 out of 20 of TQM implementation, the ISO 9001 certification should be achieved. By utilising a strategy like this, the organisations embark on both TQM implementation and ISO 9000 certification preparations. The ISO 9000 effort will also benefit from the TQM preparation phase by having the following components:

1. Objective view of organisation strength and weaknesses
2. Baseline on employees and customer satisfaction
3. Broad objectives

4. A vision with the attendant guiding principle
5. Executive level steering committee
6. Easy means of communicating with employees and other stakeholders.

2.6.4 ISO 9001 certified company embracing TQM implementation

Organisation that has already registered as ISO 9000 compliant should see the effort beginning of the TQM journey provided that ISO 9001 registration was approached as a way to improve the organisation and not a marketing tool. Such organisations must develop their TQM implementation plan, and then focus on all ISO 9000 requirements that seem to be not fulfilled by the system in its current state. After addressing all loopholes, the organisation must determine in the TQM implementation process, which step they are on and continue from that step with TQM implementation.

2.7 Theory of constraints (TOC)

Goldratt (1992:27) state that the TOC's fundamental belief is that every system, sub-system or organisation has one constraint that limits performance. He argues that, if improvement activities are implemented anywhere except on constraint, performance cannot improve due to the fact that the system is still constrained on the same level. If performance needs to be improved, effective management of capacities and capabilities of those organisations by proper constraint management is vital. The TOC's five step implementation process is:

- Identify the system's constraints – know what restricts performance.
- Decide how to exploit the system's constraints – decide how the constraints will be addressed.
- Subordinate everything else to the above decision – use the organisation's resources maximally to exploit the constraints.
- Elevate the system's constraints – the system cannot perform to infinity, as a result another constraint will arise.

2.8 Technical procedures

The objective of the QMS is to give assurance that all tasks performed to optimise the conveyor system meet the need for which they were undertaken (Montgomery, Jennings & Pfund, 2011:76). This means that the task performed adheres to relevant standards, follow procedures,

stay within budget, consume limited material (no rework), use the right skills and is completed in time. During the implementation of tasks, errors can be made which may result in a safety hazard or loss of plant performance; the QMS was a starting point to prevent this situation. The four elements of a conveyor quality system are engineering, maintenance, materials and procurement quality. Figure 7 below shows the conveyor QMS and its sub-systems.

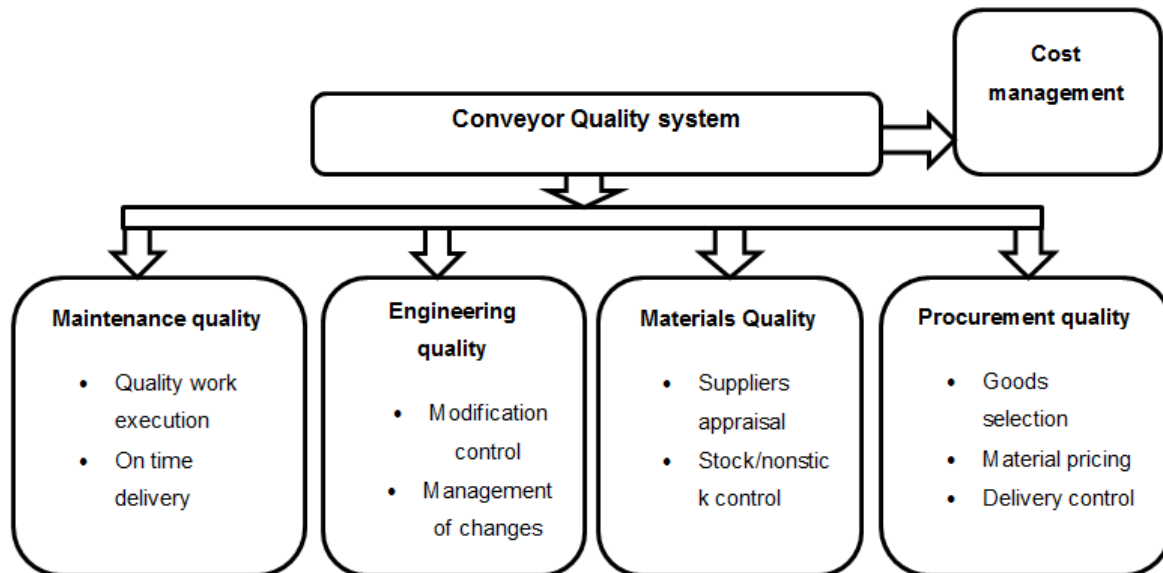


Figure 7: Conveyor quality processes (Dhillon, 2002)

2.8.1 Maintenance quality requirements (Block 1 fig 7)

Dhillon (2002:142) points out that good quality maintenance work leads to good results. Quality maintenance work can only be accurately measured against an execution plan, and the specifications or expectations. Dhillon (2002:142) also indicates that to produce good quality work, the following factors must be considered:

- Limit perplexity – ensure that the maintenance request is complete.
- Define goals – ensure that the team understands the task objectives.
- Unsafe practices – follow work procedures.
- Secondary damage – inspect the problem’s secondary damages before rectifying the problem.
- Give task feedback – information can be used for similar tasks in future.
- Replace with new parts – ensure that new parts are used for replacement.

- Avoid damaging new parts during installation – be extra careful when carrying out the installation.

2.8.2 Engineering quality (Block 2 figure 7)

Keller (2003:24) explains that if a product's performance deviates from the target performance, its quality is considered inferior. During critical system product development, an engineering design quality plan (QP) must be developed incorporating all processes and procedures with its supporting documents, required to assure delivery of the engineering work scope deliverables during production, assembling and commissioning. Keller (2003:63) points out that the engineering department is considered to be the QA department because all engineering designs must be verified and validated before they proceed to the next phase. The main focus of engineering quality includes modification control and management of changes in the conveyor system.

According to Phadke (1989:163), the objectives of the engineering modification programme are to ensure that effective management of all engineering changes occurs to maintain the integrity of the design base over the conveyor system equipment lifecycle, and to reduce business risk. This ensures that the process/procedure and tools used for design engineering changes and change management across all phases was standardised. This safeguards the engineering design done by a suitably qualified designer or system engineer, who has the training, technical qualification and expert knowledge of the plant or systems affected by the engineering changes. Changes have a major impact on the original design resulting in quality problems due to the emergence of an unbalanced system (e.g. improving performance to the expense of reliability or quality).

Phadke (1989:168) holds that engineering equipment is designed to function for a predetermined period. After this period, the owner should have plans in place to ensure that the functions of the equipment were continuously performed by either replacing the equipment or overhauling it. Managing engineering changes as equipment age has a huge impact on systems and sub-system performance.

2.8.3 Materials quality (Block 3 figure 7)

Dhillon (2002:142) explains that engineering systems have grown more complex and the cost of procuring spares has risen alarmingly. The major concern for most maintainers is the availability of the correct spares/material in time of need. This requires companies to have spares management strategies ensuring continuity of supply and managing the quality of spares procured. Dhillon (2002:143) indicated that globalisation and instant access to information, products and services have changed the way supplier and manufacturer conduct business. Today's competitive environment leaves no room for error. Companies must satisfy their customers and relentlessly look for new ways to exceed their expectations. All material spare suppliers must manage:

- Quality - how to improve it
- Cost - how to control it
- On-time delivery - how to ensure it.

Keller (2003:96) points out that having a forward-looking perspective on continuous improvement is a requirement of the competitive marketplace and the first step in becoming a world-class manufacturer/supplier. Niebel (1994:78) suggests that spares or materials used for a conveyor system can be classified according to their process impact focusing on their failure mode. The conveyor system has three types of spares namely:

- Strategic items – items that have more than six month delivery lead time and cause a conveyor system to stop operating when they fail.
- Critical items – items that affect production, safety and environment when they fail, but allow the conveyor system to function.
- Operational items – Items that do not affect production directly, but could cause secondary damages to the equipment.

2.8.4 Procurement quality (Block 4 figure 7)

Farrel (1981:178) indicates that procurement is a key function in management of a business with emphasis on total cost of ownership and specifications of what is purchased. It is also affected by inventory levels and has an important role with respect to stocks of raw material, and brought in parts especially in times of rapid inflation. This includes managing the internal and external environment to obviate unnecessary costs.

Cali (1993:35) points out that organisations spend considerable sums of money investing in the procurement of spares/materials from various manufacturing companies throughout the world, but evaluation of product-specifics and quality information is often lacking. According to Baily and Farmer (1990:69), the purchasing objective is to procure goods of right quality, right quantity, at the right time, from the right supplier and at the right price.

Most organisations limit the manufacturing process inspection to their suppliers to save cost and end up incurring higher costs. Without a proper procurement QA system, organisations run the risk of procuring substandard products which can lead to premature failure. The time or pace it takes to discover errors in the procurement process is directly related to the amount of money required to fix the error, meaning that is cheaper to correct errors earlier than later.

2.9 Quality tools and techniques

Foster (2010:316) explains that quality tools and techniques are an important component of a QMS. Measuring process performance is achieved by utilising tools and techniques interpreting data produced by the process. Evans and Lindsay (2014:606) points out that inappropriate measures lead to actions incongruent with strategies even when they are well formulated and communicated. According to Evans and Lindsay (2014:607), appropriate measures lead to the attainment of strategic goals and have an impact on the goals and strategies needed to achieve them. Effective performance measures aligned with business strategy are driven by internal and external factors shaping the company operating environment,

2.9.1 Brainstorming (nominal group techniques)

Nominal group technique (NGT) is a structured brainstorming technique that is used to produce a large number of ideas pertaining to an issue while ensuring that all the group members have equal participation in the development of ideas. NGT is an interview technique where participants work in the presence of each other but write ideas independently rather than stating them verbally (Macphail, 2001). It is not only used to generate a large number of ideas, but also to prioritise the ideas and consequently the ideas that receive the majority of votes can be selected.

2.9.2 Pareto principle

According to Foster (2010:331), Pareto indicates that he had the insight to recognise that in the real world, a minority of causes lead to the majority of problems. The Pareto principle utilises the Pareto analysis also known as the 80:20 rule to analyse data. According to this rule, 80% of problem originate from 20% of causes. The graphical tool used in the Pareto analysis is called the Pareto chart, which is a bar chart displaying the comparative significance of problems in a format which is easy to interpret. Figure 8 below shows a conveyor system Pareto chart

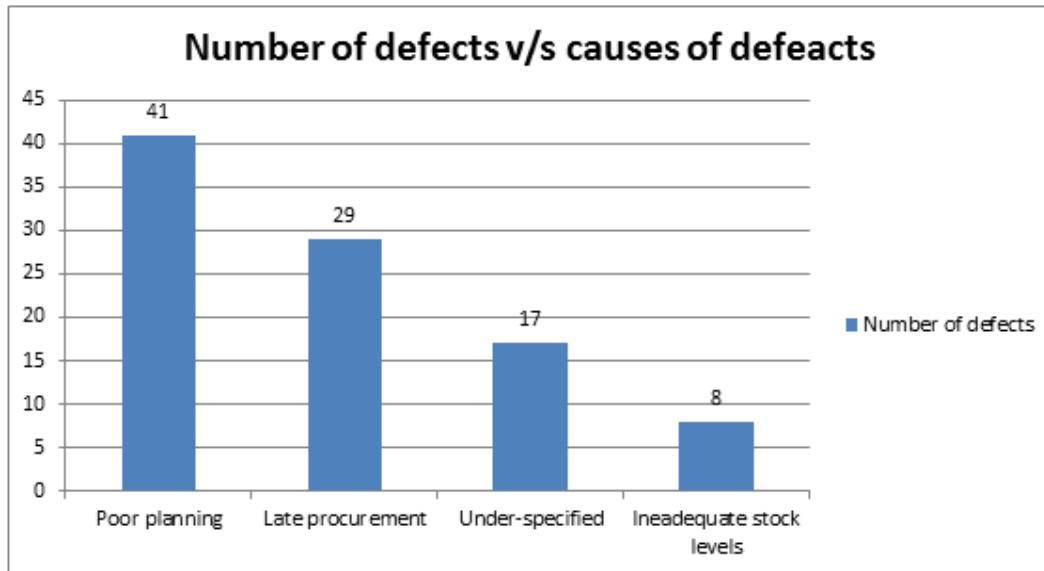


Figure 8: Pareto chart for a conveyor system (Goetsch & Davis, 2013)

2.9.3 Cause and effect diagrams

According to Keller (2003:314), the cause and effect diagram can be used to identify and isolate the causes of a problem. The cause and effect diagram is the only quality tool that is not based on statistics because it is purely based on visualising how the various factors associated with a process affect the process output. The benefits of using cause and effect diagrams are that diagrams can be used with any problem, can separate causes from symptoms and group information reducing irrelevant information. The cause and effect diagram can show all the possibilities that can cause quality problems on a system as shown Figure 9 below.

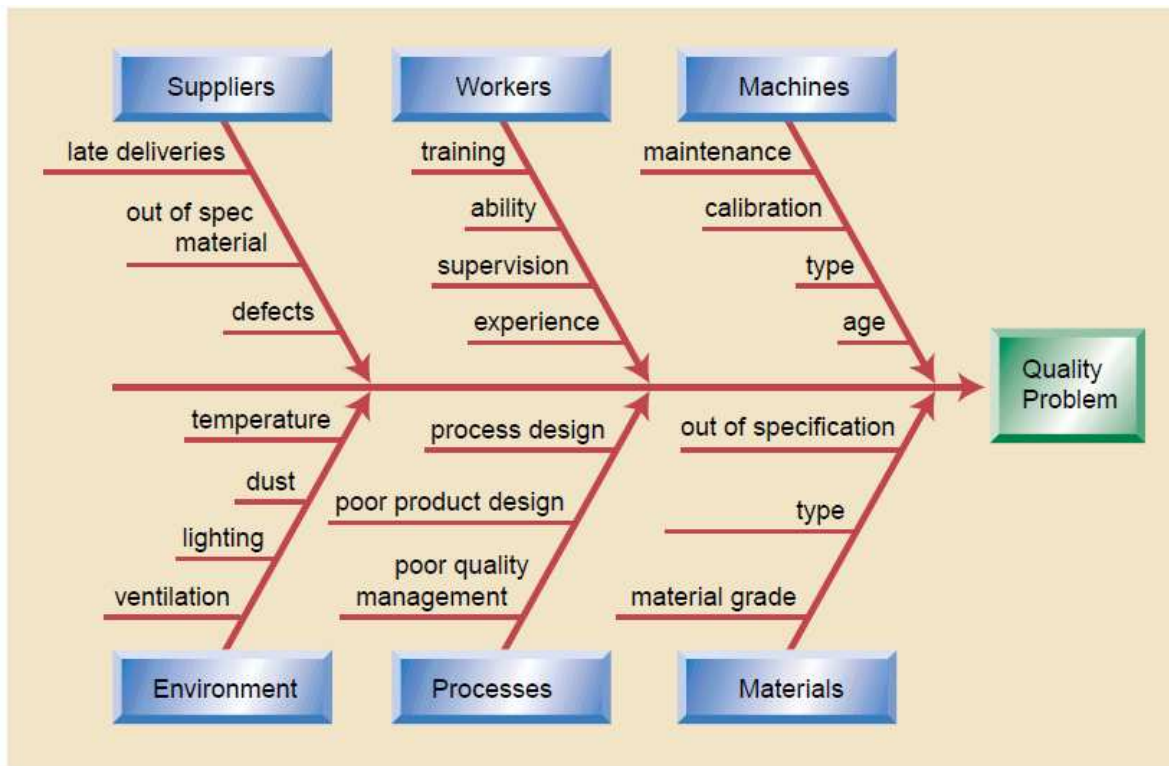


Figure 9: Cause and effect diagram for a conveyor system (Foster, 2010).

2.9.4 Control chart

According to Goetsch and Davis (2013:263), the control chart developed by Shewhart from Bell Laboratories, separates the special causes from common causes using statistical techniques. With these techniques, data is plotted over time like a run chart with the difference that data stays between the upper control limit (UCL) and the lower control limit (LCL), varying about the centreline or average so long as the results of common causes. When special causes exist in the process, the process goes out of control (below or above average limits). Control charts are appropriate tools to monitor processes and alert users when the processes are out of control.

Goetsch and Davis (2013:312) point out that although statistical process control was developed for industrial applications, the concept can be implemented for any process because all process are affected by multiple factors. The X chart concentrates on variations from the average over time while the R chart focuses on variations of each sample over time.

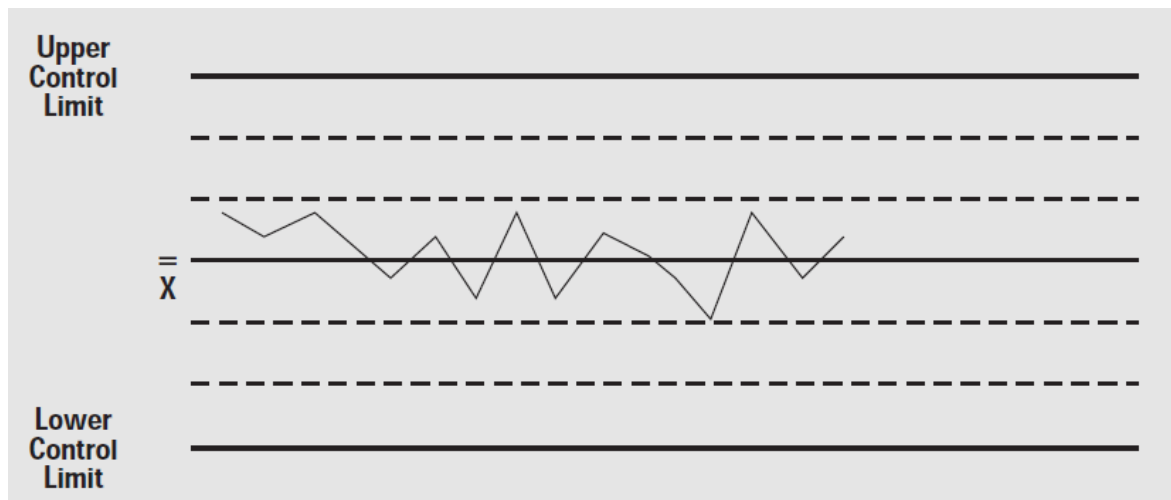


Figure 10: Process control chart (Montgomery, Jennings & Pfund, 2011)

Montgomery, Jennings and Pfund (2011:232) point out the following three widely used control charts:

- control chart of fraction not conforming (P chart)
- control chart for non-conformance (C chart), and
- control chart for non-conformities per unit (U chart) which is useful in situations where the average number of non-conformities per unit is a more convenient base for process control.

These control charts can be used to control the occurrence of a number of equipment defects.

According to Montgomery, Jennings and Pfund (2011:261), process improvement is the principal objective of any statistical process control. The application of a control chart will provide information on two key aspects of the process, namely statistical control and capabilities. The technical capability of a process can only be adequately assessed when statistical control has been established.

According to Stamatis (2003:106), in reference to data collection techniques, the data accuracy is of overriding importance because it is information that drives decisions identifying solutions to problem as output to analysis outcome. Montgomery, Jennings and Pfund (2011:262) point out that using electric data control (software) to collect information has improved the accuracy of charts compared to manual means.

2.9.5 Design experiment

According to Oahland (2003:337), quality improvement is most effective when it is an integral part of the service/product realisation process. Oahland points out that design experiments are tests where purposeful changes are made to input variables of a process so that observations can be made to similar changes in the output. The process variables contain controllable factors and uncontrollable factors. Figure 11 below shows a general model of such a process.

The objective in many cases is to develop a robust process minimally affected by external sources of variability. A well-designed experiment is important because the results and conclusions that can be drawn from the experiment depend to a large extent on the way in which the data were collected. In general, experiments are used to study the performance of processes and systems. The objectives of the experiment may include the following:

- Determining which input variables are most influential in the output response.
- Determining where to set the influential input so that output is almost always near the desired nominal value.
- Determining where to set the influential input so that variability in output is small.
- Determining where to set the influential input so that the effects of the uncontrollable input variables are minimised.

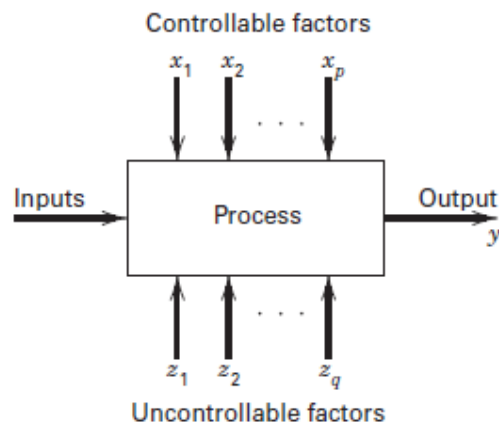


Figure 11: General model of a process (Oahland, 2003)

Montgomery (2005:328) argues that the three basic principles of experimental design are:

- Randomisation – a good trial diminishes the variability of the estimation and provides neutral evaluation of the mediation by avoiding confusion from other factors, which are known and unknown. Statistical methods necessitate that the observations (or errors) be self-sufficiently disseminated random variables. By accurately randomising the experiment, we also assist in averaging out the effects of extraneous factors that may be present.
- Replication – an independent repeat of each factor combination. Replication has two important properties. First, it allows the experimenter to obtain an estimate of the experimental error. This estimate of error becomes a basic unit of measurement for determining whether observed differences in the data are really statistically different. Second, if the sample mean is used to estimate the true mean response for one of the factor levels in the experiment, replication permits the experimenter to obtain a more precise estimate of this parameter.
- Blocking – this is a design technique used to improve the precision with which comparisons among the factors of interest are made. Blocking is often used to reduce or eliminate the variability transmitted from nuisance factors namely factors that may influence the experimental response, but in which we are not directly interested.

2.9.6 Factorial design

According to Montgomery (2005:337), experimental design is a critically important engineering tool for improving any process. It also has extensive application in the development of new processes. Application of these techniques early in process development can result in:

1. Improved performance, profit or results
2. Reduced variability and closer conformance to the nominal
3. Reduced development time
4. Reduced overall costs.

Experimental design methods can also play a major role in engineering design activities, where new products/processes are developed and existing ones improved. Designed experiments are widely used in design. Figure 12 below shows high (+) levels and low (-) levels of their controllable effects for three factorial experiments with their interacting effects.

	A	B	C	AB	AC	BC	ABC
(1)	-	-	-	+	+	+	-
a	+	-	-	-	-	+	+
b	-	+	-	-	+	-	+
ab	+	+	-	+	-	-	-
c	-	-	+	+	-	-	+
ac	+	-	+	-	+	-	-
bc	-	+	+	-	-	+	-
abc	+	+	+	+	+	+	+

Figure 12: All contrasts for a three factorial design (Montgomery, 2005)

Montgomery (2005:343) provides a framework of the commended procedure replicated. Utilising this approach, it is necessary that everyone involved in the experiment have a clear idea in development of the objective of the experiment, exactly what factors are to be studied, how the experiment is to be conducted, and at least a qualitative understanding of how the data will be analysed.

2.9.7 Analysis of variance (ANOVA)

Montgomery (2005:345) points out that ANOVA is a statistical technique used extensively to analyse data that results from designed experiments. By judging the significance of effects, the ANOVA is a formal way to determine which effects are non-zero. Two other methods are useful. In the first method, we can calculate the standard errors of the effects and compare the magnitude of the effects to their standard errors. The second method uses normal probability plots to assess the importance of the effects. The ANOVA is the verification and validation tool used to analyse results of the factorial experiments so that the trivial many can be separated from vital few. The calculations include calculating the sum of squares, mean squares, normal and predicted residual values and effects sum of squares.

2.10 Process approach to quality management

Oahland (2003:12) indicates that a process is the transformation of a set of inputs into outputs that satisfy customer needs and expectations. Clearly, to produce an output that meets the requirements of the customer, it is necessary to define, monitor and control the inputs to the process, which in turn may be supplied as output from an earlier process.

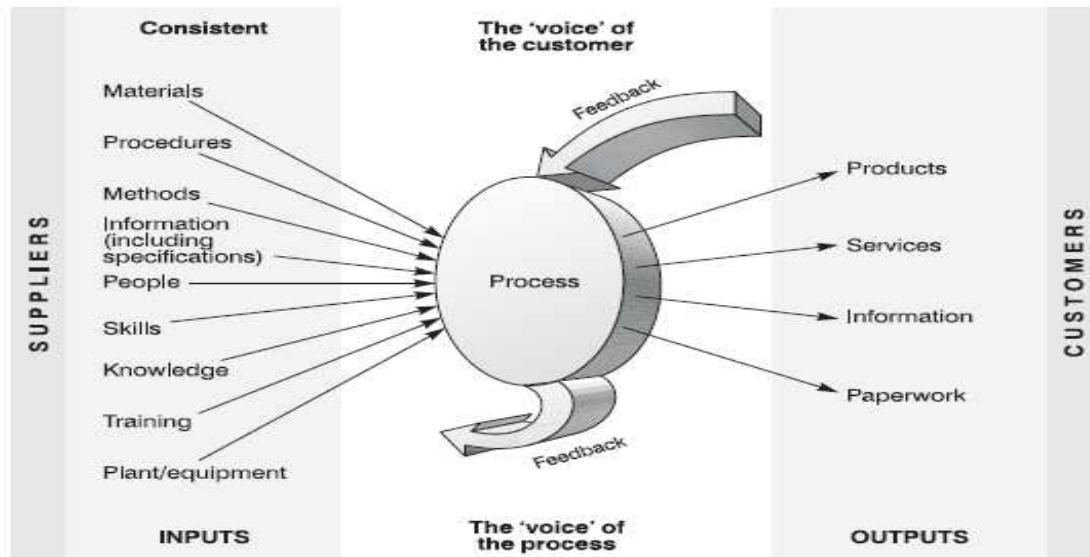


Figure 13: Process approach to quality management (Oahland, 2003)

2.11 Structure and quality management

Jurca (1999:4) points out that structure constitutes orderly arrangement of power, obligation and liaison management within functions. The basic requirements of a quality model is to ensure: that one source of information informs management, that sound job preparation occurs, work procedures are adhered to, management of costs, monitoring of contractual work, and provision of adequate equipment specifications for new purchases.

Foster (2010:128) suggests that the use of documented work instructions and procedures on all critical activities contain the purpose and scope of an activity covering what will be done, when, where, how, what material, by who (skills) and how information will be controlled and recorded. QMS trends were orientated towards process management, which was fully verified and validated. For maintenance quality systems to operate optimally, sufficient resources must be allocated. The major maintenance resources required include skilled personnel, availability of technical data, proper tools, diagnostics instruments, spares and finances.

2.12 Levels of quality

Bertels (2003: 109) states that the effective implementation of the QMS on conveyor systems is very central to its entire process performance. In an organisation, the QMS which originated from the quality policy must be divided into three levels namely:

- Organisational level (strategic) – concerned about meeting external customer and stakeholders requirements.
- Process level (functional level) – concerned about meeting internal customers' requirements focusing on processes that take the organisation closer to its goals.
- Performer level (operational) – concerned about meeting task process requirements. More focus on task/process improvement, accuracy, completeness, innovation, timelines and cost.

Figure 14 below shows three levels of quality in an organisation.

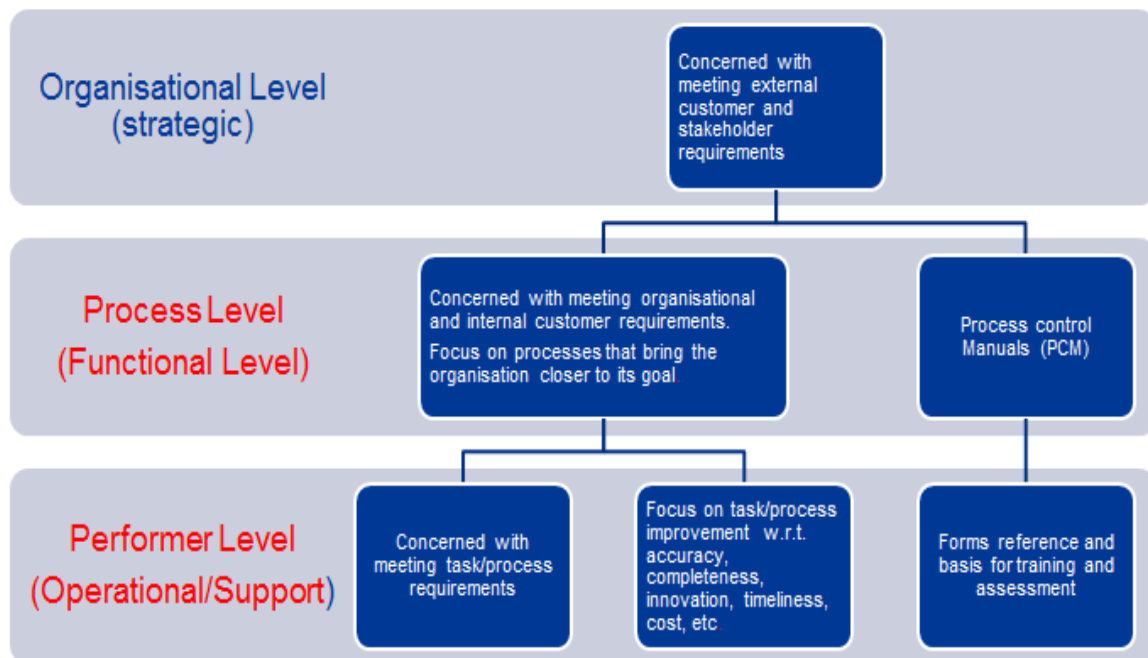


Figure 14: Three levels of quality in an organisation. (Tjabadi, Steyn & Flaherty, 2012)

The conveyor QMS falls under the process (functional) and performer level (operational) concerned with satisfying process requirement and achieving the desired requirement. This focuses on the process improvement opportunities and the process accuracy which is required to operate efficiently while being effective. According to Bertels (2003:246), quality management

processes when fully implemented, must align with customer needs by translating requirement into goals, implement business strategy by adhering to strategic objectives, encourage fact-based thinking, integrate the entire process and manage process life cycle improving proactively.

2.13 Quality documents and records

According to Taylor (2009:187), the quality manual is the first level 1 documentation in a QMS. The quality manual describes the scope of a QMS, explains every requirement and identifies all exclusives. The quality manual is primarily used to communicate management expectations to employees, to ensure that the organisation complies with standards, and to serve as a measure of compliance to audits. Procedures are level 2 documents, work instructions are level 3 documents, and quality records are level 4 documents. Figure 15 shows the quality documentation and referencing.

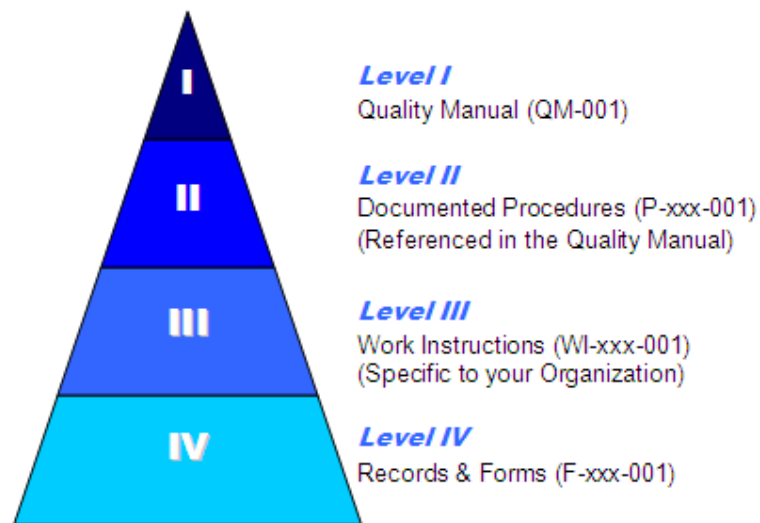


Figure 15: Quality documentation and referencing (Taylor, 2009)

2.14 Verification and validation

Systems engineering defines verification as “actions used to test accuracy of any element (task, service, system, requirements)”. Objective evidence is required to prove that desired results

were achieved. Systems engineering defines validation as “activity that ensures and provides confidence that the system will accomplish its intended use”. The purpose of validation is to establish output compliance compared to input.

North-West University's Faculty of Engineering defines verification as “confirming that a suggested solution to a problem is properly applied”. North-West University's Faculty of Engineering defines validation as “confirming that the suggested solution to the problem essentially solves the problem”. The concern is the end product. Both definitions focus on ensuring that the proposed solution will actually solve the problem.

With the above definitions in mind, the investigator must be clear about defining the problem and its desired solution so that the research design can be continuously verified and validated against the requirements. The researcher must plan his/her research design in such a way that verification and validation becomes part of every milestone aimed at ensuring that deviation can be identified and addressed quickly.

In this research, the research hypotheses were verified by conducting a brainstorming session to affirm whether the problem was legitimate. The researcher validated this research document by determining whether it provides solutions for quality problems in the ash plant and if the solution is fit for the purpose.

2.15 Critical analysis

According to a study by Lisai (2007:33) titled “Implementing a QMS at statistics Sweden”, process improvement tools have common features. They all indicate that processes can always be improved, assume that statistical measurements are key for improvement, and believe in employee closest to the process. According to a study by Asiri (2000:28), titled “Implementation of the ISO 9000 system in manufacturing”, it was found that ISO 9000 was vital to resolving quality problems in the United States of America's car manufacturing sector with a success rate of 88%. According to a study by Deming, titled “Total quality in Japan”, Japanese manufacturers have embraced TQM and have become world leaders in the manufacturing sector, improving by 18% in 2004.

It was also confirmed by Deming (2013:239) on his book titled “Quality management for organisational excellence”, that TQM and ISO 9000 support each other and have an above 90% success rate. The TOC also works well with TQM and ISO 9000. A study by Denut titled “When performance matters most”, proves that the TOC works well to identify, verify and validate the

constraints before embarking on a project to elevate the constraints, especially in areas where identifying a constraint is challenging. TOC also assists in identifying elements of a QMS system that has created a constraint in other areas of the business.

According to a study by Muhammad (2004) titled "Five steps for more effective implementation of brainstorming in value engineering studies", the nominal group technique (NGT) brainstorming has resolved several technical and non-technical complex problems by generating a lot of ideas in a short period of time. Examples include the APOLLO II missions from the moon landing in the sea. American and Indian manufacturing firms have also gained a great deal of information about their manufacturing processes, which was used for continuous improvement.

According to a study by Kumar (2008:51), titled "Application of root cause analysis in improvement of product quality and productivity", the Indian cable manufacturing sector has improved its performance from 55% to 77% between 2006 and 2008. The technique was also proven to be successful with oil rigging companies such as Shell and British Petroleum.

A study by Ahmad (2011:87) titled "An Application of Pareto analysis and cause-and-effect diagram (CED) for minimising rejection of raw materials in lamp production process" indicates that cause and effect combined with Pareto analysis, eliminated the dimensional defects in the cutting operation of the Oxy-Fuel Cutting Machine in Canada, reducing the rejection rate from 11,87% to 1,92% on an average within a year.

A study by Flaig (2004:109) titled "A new classification of variables in design of experiments", indicates that factorial design has the ability to solve all manufacturing problems where input process variables can be adjusted. A study published by Montgomery (2010:10) titled "Factorial design to resolve wire cooling", showed that factorial design has an advantage over other methods because it provides all the possible combinations, giving more information about a problem and its causes.

Chapter 3: Experimental Design

This chapter presents a detailed research methodology carried out in three sections. In the first section, technical investigations were carried out using brainstorming, cause and effect diagrams and Pareto analysis. In the second section, a research survey was carried out using questionnaires addressing the management part of the problem. In section three, three factorial experiments focusing on the ash process/plant part of the problem were carried out.

3.1 Introduction

Montgomery (2005:346) points out that planning an experiment requires decisions to be made on what measurements to make (the responses), what conditions to study (the treatments) and what experimental material to use (the units). The research experiment had three sub-sections to satisfy the research question: What is the root cause of conveyor failure (unreliability) in the ash plant? (Section 1); is the management system effective? (Section 2), and whether the ash plant was operating within its design process parameters (Section 3). The three sections led to three design experiments and collecting sources to address each separately:

1. A brainstorming session, cause and effect diagram and Pareto analysis to address the technical side focusing on system maintainability. The objective of this methodology was to determine whether causes if addressed would resolve most of the conveyor system technical problems. This was not limited to technical issues only, but also included all support functions needed to support technical performance, for example procurement, materials management and finance.
2. A Survey questionnaire was design to address the system side focusing on management or leadership. This section focused mainly on perceptions of the research populations towards a QMS (ISO 9000) and its effectiveness in the ash plant. This survey questionnaire also focused on identifying barriers of TQM implementation in the ash plant which will be used to measure the possibility and practicality of implementing QMS, which could be more favourable to resolve the problem.
3. Three factorial designs were considered to address the process side focusing on process stability and capabilities to deliver desired results. This part requires justification from technical data measured from the process, calculations made and conclusions made purely based on process results. Factorial design covers all conveyor operating

conditions which include ash loading conditions, ash back-logging and the impact of back-logging on the overall performance.

Figure 16 below shows the research experimental design process.

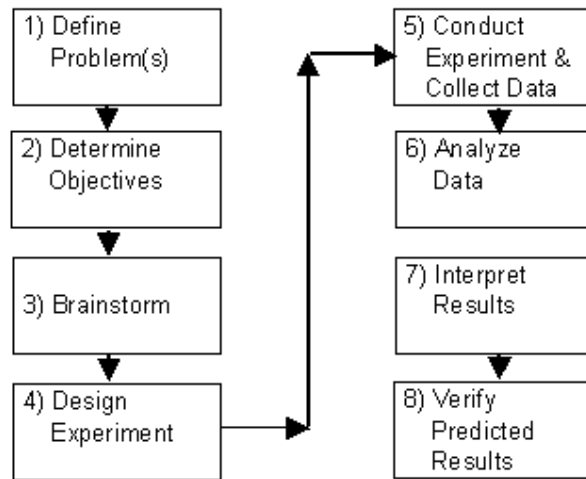


Figure 16: Experimental design processes (Montgomery, 2005)

3.2 Research method

Crotty (1998:23) points out that research (qualitative or quantitative) involves an explicit, disciplined, systematic approach to discovery, applying methods appropriate to the research question. Three research methods are:

1. Quantitative research method – an approach where the researcher uses positivist claims to develop knowledge, carry out experiments and collects data through a predetermined instrument to yield statistical data.
2. Qualitative research method – an approach in which the investigator makes knowledge claims based on constructivist perspectives. The researcher collects data with the primary objective of developing themes from the data.
3. Mixed method – combine qualitative and quantitative research methods

Crotty (1998:23) suggests that the following four questions should be considered when designing a research proposal:

1. What epistemology – what theory of knowledge informs the research? (objectivism or subjectivism).

2. What theoretical perspective – what stance lie behind the methodology in question (positivism and post-positive, interpretivism, critical theory).
3. What methodology – plan of action links methods to outcomes governs the choice and use of methods (experimental research, survey research).
4. What methods – what techniques and procedures do we propose to use.

3.3 Research design

3.3.1 Technical research methods

3.3.1.1 Nominal group technique

The nominal group technique was carried out in two stages:

Stage 1: The ash plant quality problems are introduced and the team generate ideas.

1. Define the issue – the quality issues in the ash plant were discussed, including quality of spares, quality of workmanship, quality of contracted work, delivery/supplier lead times, and unavailability of material. All quality issues were recorded, not allowing discussion about the issues at this stage, but defining all unclear terms.
2. Generate ideas – the team members were given 30 minutes to silently write down general ideas on a piece of paper provided. During this time talking to each other was prohibited to ensure that everyone recorded their own original ideas.
3. Collect ideas – papers were collected and the members' ideas were recorded in the chart-pack. During this stage of the session, no conversations or side discussions between members were allowed.
4. Clarify ideas – during this stage, all ideas were read out aloud allowing clarity if needed. Each team member was allowed to give detailed information regarding what he/she intended. Other team members were also given an opportunity to comment. At this stage, the wording and unclear statements were clarified.
5. Combine ideas - after clarifying ideas, some ideas were combined after confirmation by members that they could be combined. If the member who generated the idea disagreed at this stage, the ideas were kept separately so that information could be collected independently.

Stage 2: Make idea selections

1. Assign letters to ideas – all ideas recorded were awarded a letter so that ideas could not be confused, especially when the votes were counted.

2. Rank ideas independently – all team members were requested to write down the items using the the letters allocated to them and assign them a numeric value based on the member’s judgement on level of importance (minor or significant). The highest number assigned to the most significant and the lowest number to the least important ideas.
3. Collate the rankings – team member ratings were transcribed onto a chart pack, indicating a number next to a corresponding idea.
4. Add the rankings – the numbers per idea were added together across. The number with the highest total was the most important to the team, and became the highest priority item of the team.
5. Rewrite the list in order of priority – the list was rewritten in order of the priorities from high to low.

Perform a sanity check - after rewriting the list in order of priority, the team discussed whether the priority results made practical sense and if the implementation could be carried out as such.

3.3.1.2 Cause and effect diagram design

A cause and effect diagram was used to identify, sort, analyse and display possible causes of a quality problem or quality characteristic in the ash plant by illustrating the relationship between quality outcome and all factors that influence it. The cause and effect diagram was useful for identifying and organising the known or possible causes of quality or the lack of quality. The following steps were followed to construct and analyse the cause and effect diagram:

1. Step 1 – identify and define the effect to be analysed. The effect is poor quality at the ash plant resulting in poor conveyor system performance. The team focused on what caused quality problems in the ash plant and what would be an excellent outcome. The team also had to focus on the fallout that could result from focusing on a negative effect. Getting a team to concentrate on things that could go wrong may create a more relaxed atmosphere and enhance group participation.
2. Step 2 - draw the spine and create the effects box. The horizontal error was drawn pointing to the right indicating a spine and a description of the effect (poor quality) where the results from the process were written.
3. Step 3 - identify the main causes contributing to the effect being studied. The main causes of the ash plant quality problems that resulted in plant underperformance were identified including the categories under which the main causes were listed. The main

categories included methods, materials, machinery, people, policies, procedures, plant and environment. After the team selected the main categories, they were written on the left of the effects box, some above the spine and some below it. Boxes were drawn around each category, they were labelled and a diagonal line was used to form a branch.

4. Step 4 - for each major branch, other specific factors were identified which may be the cause of the effect. As many as possible causes and factors were identified and attached as sub-branches of the major branches with details of each cause. Minor causes that applied to two or more major causes were listed under both factors.
5. Step 5 - identify increasingly more detailed levels of causes and continue organising them under related causes or categories.
6. Step 6 - analyse the cause and effect diagram to identify causes that warrant further investigation. The cause and effect diagrams identify only possible causes of quality problems. The Pareto chart was used to determine the cause to focus on first. All causes that appear repeatedly were identified and given more attention as they were likely to be the root causes.

3.3.1.3 Pareto analysis design

Pareto analysis was used to prioritise possible quality problems. The following steps were followed:

1. Step 1: Identify and list problems – all quality problems that needed to be resolved was written down including the views of all the members involved in the brainstorming session to get their input.
2. Step 2: Identify the root cause of each problem – the cause and effect diagrams were used to identify the root cause for each quality problem.
3. Step 3: Score problems – problems were scored according to the cost of the poor quality for the section.
4. Step 4: Group problems together by root cause – common root causes were grouped together to determine a score per root cause.
5. Step 5: Add up the scores for each group – scores for each group were added together
6. Step 6: Take action - attend to the causes with the highest scores first.

3.3.2 Survey questionnaire

3.3.2.1 Questionnaire design

This survey questionnaire was designed to investigate the quality problems and analyse them in the context of ISO 9000 and TQM requirements in order to develop a tailor-made quality management plan to address the ash conveyor system problem with the knowledge that no QMS would be exactly the same.

The main purpose was to investigate whether the ash plant complied fully with the ISO 9000 requirement or complied only partially with the requirements so that the elements of non-conformance could be attended to first.

The second point was about the stage and step of the ash plant in the TQM implementation process, due to the fact that Eskom Lethabo is already an ISO 9001 certified power station.

The third point was about identifying critical factors that could lead to successful implementation of ISO 9000 in the ash plant and barriers that were encountered in the implementation process.

The fourth point was about investigating the level of knowledge about both ISO 9000 and TQM among Eskom management and staff to determine the integration level between ISO 9000 and TQM. A good research method must specify a data-collection process, an instrument development process, and a sampling process.

3.3.2.2 Research population

A research population is generally a large collection of individuals or objects that is the main focus of a scientific query. It is for the benefit of the population that researches are done. The identified research target population for this study was Eskom Lethabo employees who worked or are working (has responsibility in the ash plant) and quality managers at all Eskom thermal power stations. This included the power station manager, middle managers, line managers, engineers, technicians, artisans and planners. The following characteristics were considered in selecting the participants: occupation, years of experience, age, highest qualification and discipline.

3.3.2.3 Sending and collecting replies

The survey questionnaire was designed to be completed by the participants themselves. Questionnaires were sent and received through emails. A letter explaining what the questionnaire is about and why its completion is of value, was sent to participants with the questionnaire.

3.3.2.4 Questionnaire design

A survey (primary data source) was conducted on a randomly sampled group in the population to investigate the objectives of this study of which findings will be used to draw conclusions and make recommendations. The results were compared to the key elements of an effective QMS as explained in Chapter 2 in order to address the research objective as set out in Chapter 1.

Kothari (2004:100) indicates that the design of the questionnaire can be split into three elements: determine the questions to be asked, select the question type for each question and specify the wording; then design the question sequence and overall questionnaire layout. The questionnaire was designed to measure elements of a QMS and its requirements based on ISO 9000 and TQM literature reviews. The following steps were followed during this research project:

1. A pilot study was conducted to verify and validate the need for a research plan. Five employees which also form part of the research population were targeted for completion of an informal survey questionnaire. The aim was to establish whether the questionnaire was correctly structured and how people could relate quality to different elements or aspects on the QMS.
2. A conceptual framework was developed based on the information gathered during the pilot study including criteria for the target participants.
3. A literature study was conducted to gain knowledge about quality management systems mostly ISO 9000 and TQM which are also viewed as the current best practices in terms or quality management.
4. During the pilot study, queries were made regarding some questions and clarity was provided, which resulted in some amendments to the questionnaire. Some participants also noted that the questionnaire was straight forward.
5. The final research design was based on the pilot study and literature review results.
6. The survey was sent to participants by email and the period to complete was stipulated.

7. Data received was collected, captured and assigned correctly. Data was analysed to determine the research findings, which were used to formulate conclusions and recommendations.

3.3.2.5 Pilot survey

The questionnaire was tested with five individuals who were also part of the sampling population. The aim was to detect any problems with the questionnaire so that they could be corrected before the main/real survey. Four open-ended questions were converted into rated scale questions after identifying the range of possible answers from participants. A trial analysis was also performed during the pilot survey in order to test the analysis procedure. All amendments were made to the main questionnaire to maximise the respondent rate and minimise the error rate on answers.

3.3.2.6 Main survey

A research administrative email account was created for the purpose of this research project to make it easy to keep track when questionnaires were sent and to whom. This was updated with details of follow-up contact and reminders of due dates. Each questionnaire was uniquely identified (01600 to 01640) before it was distributed and a spreadsheet with all the names and number of participants was kept. All questionnaires received were saved in a research folder using its unique identification number as file name. This made it easy to see when questionnaires were not returned. The questionnaires were administered through lalamanibudeli@gmail.com and were completed within one month.

3.3.2.7 Validity of the test instrument

According to Kothari (2004:81), research test instrument validity refers to the degree to which the instrument represents a concept of the measured research. Validity is concerned with the extent to which an instrument measures what it is intended to measure. Quantifying research variables measurement involves operationalisation of contrasts in defined variables and the development and application of instruments or tests. A measure is said to have content validity only if there is general agreement among experts that the instrument covers all aspects of the item being measured.

According to Kothari (2004:81), the reliability and validity of the measures are key indicators of the quality of a measuring instrument. The test instrument was evaluated in this research for content validity. The research plan, which included a copy of the research proposal, was sent to the North West University's statistical committee members and to consultants in ISO 9000 quality management systems within Eskom to review the test instrument and determine how well the chosen items represented the defined constructs.

Based on the suggested clarifications, revisions, recommendations and criticisms, some modifications were made to improve the test instrument. The major change was that another piece of survey was included to measure the barriers for implementing TQM within the Lethabo Ash Plant.

3.3.2.8 Reliability of the test instrument

Reliability refers to the instrument's ability to provide consistent results in repeated use. Three methods were used to measure reliability of the test instruments:

- test-retest or alternative test method,
- internal consistency, and
- split-halves method.

The internal consistency method is the most common measure in which individual items of the scale should all be measuring the same construct and is highly inter-correlated. Kothari (2004:87) notes that the reliability of an instrument is closely associated with its validity; an instrument cannot be valid unless it is reliable. However, the reliability of an instrument does not depend on its validity. Responsiveness is the ability of a measure to detect change over time in the construct of interest.

Cronbach's coefficient is the most widely used objective measure of reliability (internal consistency). The generally agreed upon lower limit for Cronbach's alpha is 0.70. An internal consistency analysis was performed to assess the reliability aspects of Likert Scale variables. The Cronbach's alpha range was between 0.6896 and 0.8867. The summary of the reliability analysis is given in Table 3 below. The alpha values indicate that the test instrument of this study is a sufficiently reliable measure.

Table 3: Cronbach's alpha range

Construct	No of Items	Alpha Value
Management Leadership	6	0.756
Measurement and Feedback	5	0.837
Continuous Improvement	4	0.778
Supplier Quality Management	5	0.832
Systems and Processes	4	0.715
Education and Training	4	0.794
Work Environment and Culture	4	0.745
Barriers to TQM implementation	15	0.764

3.3.2.9 Response rate

Thirty seven (37) questionnaires were sent out. Thirty three (33) completed survey questionnaires were returned. Four (4) participants were contacted with regard to unreturned questionnaires, of which three (3) could not be received within the revised deadline. The respondents were shift workers which made it difficult to get hold of them. Out of the received questionnaire, two (2) could not be used because of incomplete data. The participants were contacted to verify of the uncompleted field and the participants could not be reached. Out of thirty seven (37) surveys, only thirty two (32) were used for the analysis of the research. The response rate is summarised in a Table 4 below:

Table 4: Questionnaire response rate summary

Column 1	Column 2	Column 3
Description	Number	Percent
Distributed questionnaires	37	100%
Received questionnaires	34	92%
Usable questionnaires	32	86%

3.3.2.10 Data analysis techniques

All data received was stored in one excel database for manipulation purposes. Statistical methods were used to analyse interpreted data collected through the survey questionnaires, including factor analysis, measuring variation, measuring association and descriptive statistics.

1. The descriptive design was chosen due to its ability to analyse single variables and rank measured variables within each concept, indicating the current context of ISO 9000 implementation in the ash plant.
2. Correlation tests purpose is to find out if there is a relationship and an extent of the relationship. Correlations close to +1.0 (or -1.0) designate strong positive (or negative). Correlations close to 0 designate little or no relationship between two variables.
3. Factor analysis was used to detect the structure of the relationships between variables and find underlying categories that best describe the construct.
4. The Chi-Square test was used to measure variations mainly to test any significant differences between groups or variables. It is useful as a general test to check whether significant differences exist between groups in contingency tables; only when the distance is less or equal to 0.05, it is considered significant.

3.3.3 Factorial design

3.3.3.1 Factorial experiment

Three factorial designs were developed to analyse the impact of process performance on quality improvement, focusing on ensuring continuous ash transportation capacity. The objective was also to improve the process by identifying the best possible combination that would deliver a balanced conveyor system capable of delivering the desired output carried out by varying controllable inputs and observing the impact on the output.

The ash plant conveyor system is designed to operate at a minimum speed (X1) of 1 m/s and a maximum speed 2.87 m/s. The throughput time (X2) is the number of hours that the ash system runs without accumulating any ash backlog, which by design should be a minimum of seven hours to a maximum of 24 hours per day. The ash capacity (X3) is the amount of tons that the system was transporting per hour which by design is a minimum of 650 t/h to a maximum of 2060 t/h. The formula below is used to calculate output from each combination of factors.

Formula: $y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \phi_{ijk}$

Where Y is responses, μ is an overall mean, α is row effects, β is Column effects, $\alpha\beta$ is interaction effects, ϕ is random errors. The three factorial experiments compare all possible combinations between minimums and maximums varying from one factor and recording the output response based on the input change.

3.3.3.2 Conduct experiment

The experiment was setup to measure process parameters required to calculate the performance of the conveyor system over a certain period. The active factory (supervisory control and data acquisition) database was used to record and view plant real-time data including operating speeds, conveyer load, downtime, uptime, operating times and breakdown rate per equipment. Relevant data tags were trended for the duration of the experiment. A special history page was developed on this real-time data database to display experiment data from 3 July to 27 July (duration of the experiment). The three factorial experiments which contain three main effects and four interaction effects were carried out as follows:

1. The controllable input variable was varied to all treatment levels
2. Uncontrollable variables were fixed for the duration of the experiment
3. The output variables were measured to determine the output variability
4. Calculate probability values
5. Calculate the effects on output per change in input variable
6. Calculate sum of squares (SS) using formula
7. Calculate the analysis of variance (ANOVA)
8. Plot main effects and interacting effects then interpret results.

3.4 Verification and validation

Brainstorming, cause and effect and Pareto analysis has identified factors that are leading to poor quality management in the ash plant. Those factors were used to validate the ash plant elements of ISO 9000 system documents and its ability to eliminate quality problems.

3.4 Critical analysis

The research design was carried out as per research design. The research procedures were benchmarked with the procedure in an article titled "Research design: qualitative, quantitative, mixed methods" by Creswell (2003:5), which explain the do's and don'ts of conducting research. It was evident that all research procedures explained in this chapter all meet the research design requirements explained in the book. It was also emphasised that proper research design makes the actual work easier due to an absence of major errors.

Chapter 4: Results

Chapter 4 presents research results including detailed analysis of how data was explored from the experimental design. The participants' responses to each research method were examined using appropriate measures for a specific method. (Likert scale, standard deviation, mean values and ANOVA)

4.1 Introduction

This chapter focuses on the experimental analysis carried out to evaluate process input that had a significance impact on the output and the target levels of those inputs so that the desired results could be achieved (improving performance and throughput time).

4.2 Technical failure

4.2.1 Brainstorming session results (nominal group technique)

During the brainstorming session, many ideas were discussed and viewed as contributing to the ash plant conveyor system's unavailability and unreliability. The following ideas were recorded by the group as a summary of the main problems:

1. Downtime due to spares that were not available
2. Poor modification control (modifications not following the process)
3. Rework due to poor workmanship
4. Sub-standard material
5. Secondary plant damages (taking too long to stop the plant and address defects)
6. Lack of correct tools
7. Lack of plant optimisation
8. Lack of technical know-how
9. Inadequate stock level.

Table 6 below shows the final outcome of the brainstorming session. This session was a good tool to collect input and feedback from diverse employees in a short space of time. It also indicated that the relationship between conveyor speed, operating hours and actual tons of ash transported to the ash plant needed further investigation in this study which was then the focus of the factorial experiment.

Table 5: Ash plant brainstorming session results

Ash plant brainstorming session	Points accumulated	Date: 9/04/2015
Group ideas		Attendees
1. Develop and monitor critical spares weekly	13	Operations Manager
2. Re-budget and give priority based on plant impact, weekly monitored	12	Production Manager
3. Buyer appointed specifically for ash plant	11	Maintenance Manager
4. Development of specification of all critical spare (made stock items)	10	Engineering Manager
5. Book core crew for critical training	10	Engineers x 3, Snr Engineer X 1
		Technicians x 3, Snr Technician X 2
		Planners X 2
		Procurement and Materials Manager
Total attendees		17

4.2.2 Cause and effect diagram results

The cause and effect diagram was constructed with all aspects that affect the conveyor system performance. Figure 17 below shows the construction of the cause and effect diagram for conveyor system unavailability.

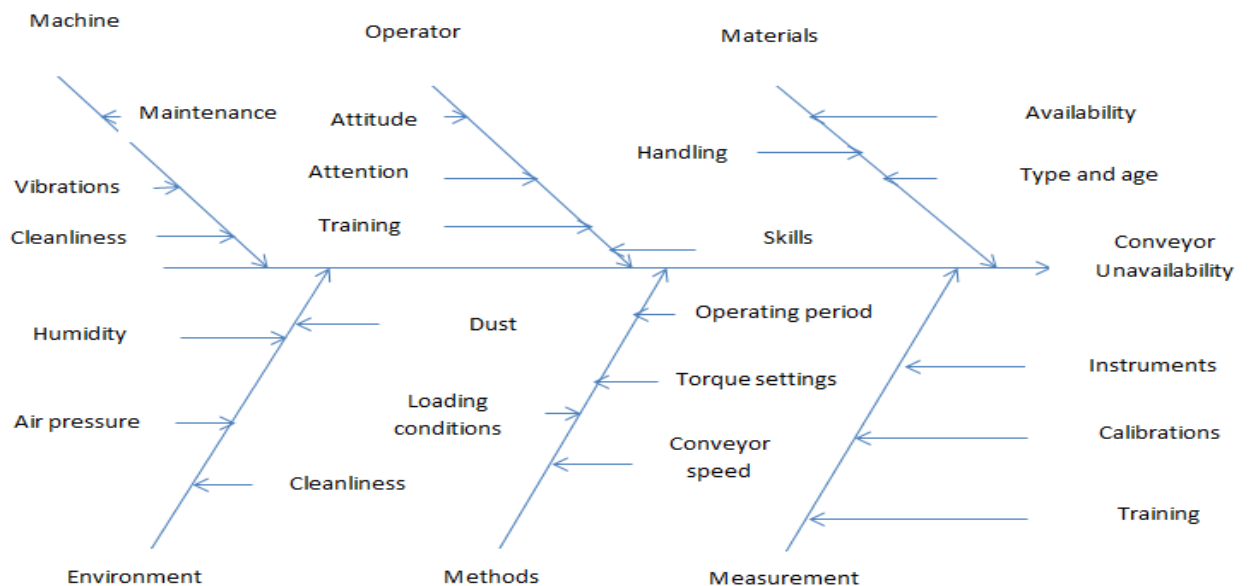


Figure 17: Cause and effect diagram of a conveyor system unavailability

4.2.3 Pareto analysis

The results of the Pareto analyses are presented in Table 6 below:

Table 6: Defects identified for each problem

No	Problem (step 1)	Cause (Step 2)	Defects (Step 3)
1	Downtime due to spares that are not available	Poor maintenance practices	27
2	Conveyor system speed control and ash loading conditions	Poor engineering controls	17
3	Modifications not updated on SAP	Poor engineering controls	4
4	Rework due to poor workmanship	Lack of training	5
5	Substandard material	Poor spare quality management	3
6	Secondary plant damages	Production pressure	2
7	Lack of correct tools	Resource unavailability	4
8	Lack of plant optimisation	Resource unavailability	2
9	Lack of technical know how	Lack of training	2
10	inadequate stock level	Poor maintenance practices	9
		Total	75

Table 7 below shows defects grouped according to their root causes.

Table 7: Defects grouped by root causes results

Causes of defects	Number of defects	Same root cause
Poor maintenance practices	36	1,10
Resource unavailability	8	7,8
Lack of training	7	9,4
Poor engineering controls	21	2,3
Poor spare procurement quality management	3	5

4.3 Management systems

4.3.1 Management system requirements survey results

All questions in this section were shortened to fit in the results table below, for detailed question check appendix 8 (survey questionnaire). The questionnaire addressed two requirements which were:

1. The level of perceived importance of the QMS elements on a five point Likert scale ranging from 1 = not important at all, 2 = not important, 3 = neutral important, 4 = important and 5 = very important.
2. The extent or degree of practice the particular elements receive in a day to day ash plant operation. This was also ranked on a Likert scale ranging from 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high.

4.3.1.1 Management and leadership

Calculated

Importance chi-square value = 5.328, df = 5, P= 0.377. The p-value is 0.377175. The result is not significant at $p < 0.05$.

Practiced chi-square value = 5.286, df = 5, P=0.382). The p-value is 0.381982. The result is not significant at $p < 0.05$

Table value

At 5% chi-square value =11.070, df = 5, P=.0.05. The p-value is 0.05001. The result is not significant at $p < 0.05$.

At 1% chi-square value =15.086, df = 5, P=0.01. The p-value is 0.010001. The result is not significant at $p < 0.01$.

Table 8: Management and leadership results

F1: Management Leadership	Important				Practised			
	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:Business objectives known	4.44	0.73	0.53	0.68	2.92	1.12	1.25	1.05
Q2:Staff involvement	4.67	0.50	0.25	0.47	2.89	0.93	0.86	0.87
Q3:Employees empowered	4.11	0.78	0.61	0.74	3.00	0.50	0.25	0.47
Q4:Communication links	4.78	0.67	0.44	0.63	3.44	0.53	0.28	0.50
Q5:Management care	4.56	0.53	0.28	0.50	3.33	0.50	0.25	0.47
Q6: Social responsibility	4.67	0.71	0.50	0.67	3.67	0.87	0.75	0.82
Average	4.54	0.65	0.44	0.61	3.21	0.74	0.61	0.70

4.3.1.2 Resource management

Calculated

Importance chi-square value = 4.260, df = 4, P=0.372 . The p-value is 0.371961. The result is not significant at $p < 0.05$.

Practiced chi-square value = 4.230, df = 4, P=0.376. The p-value is 0.375773. The result is not significant at $p < 0.05$

Table

At 5% chi-square value =9.488, df = 4, P= 0.049. The p-value is 0.049994. The result is significant at $p < 0.05$.

At 1% chi-square value =13.277, df = 4, P= 0.009. The p-value is 0.009999. The result is significant at $p < 0.01$.

Table 9: Resource management results

	Important				Practised			
F2: Resource Management	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:Human resource ability	4.56	0.53	0.28	0.50	4.11	1.17	1.36	1.10
Q2:Training provided	4.67	0.50	0.25	0.47	4.11	0.93	0.86	0.87
Q3:Employees given tools	4.67	0.50	0.25	0.47	3.78	0.97	0.94	0.92
Q4:Sufficient Finance	4.38	0.74	0.55	0.70	4.22	0.67	0.44	0.63
Q5: Effective material management	4.44	0.73	0.53	0.68	2.78	0.83	0.69	0.79
Average	4.54	0.60	0.37	0.56	3.80	0.91	0.86	0.86

4.3.1.3 Measurement and feedback

Calculated

Importance chi-square value = 4.235, df = 4, P=0.375. The p-value is 0.375135. The result is not significant at $p < 0.05$

Practiced chi-square value = 4.242, df = 4, P=.00. The p-value is 0.374244. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 9.488, df = 4, P=0.049. The p-value is 0.049994. The result is significant at $p < 0.05$

At 1% chi-square value =13.277, df = 4, P= 0.01). The p-value is 0.009999. The result is significant at $p < 0.01$.

Table 10: Measurement and feedback results

	Important				Practised			
F3: Measurement and Feedback	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:Customer satisfaction	4.56	0.73	0.53	0.68	3.22	0.44	0.19	0.42
Q2:Quality data collected	4.33	0.71	0.50	0.67	3.44	0.73	0.53	0.68
Q3: Financial performance	4.44	0.73	0.53	0.68	4.33	0.71	0.50	0.67
Q4:Employees views	4.56	0.73	0.53	0.68	3.22	1.20	1.44	1.13
Q5:Employee performance	4.44	0.73	0.53	0.68	4.22	0.44	0.19	0.42
Average	4.47	0.72	0.52	0.68	3.69	0.70	0.57	0.66

4.3.1.4 Continuous improvement**Calculated**

Importance chi-square value = 3.720, df = 3, P=0.29. The p-value is 0.29333. The result is not significant at $p < 0.05$.

Practiced chi-square value = 3.179, df = 3, P= 0.365. The p-value is 0.364842. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 7.815, df = 3, P= 0.049. The p-value is 0.049994. The result is significant at $p < 0.05$

At 1% Chi-Square value = 11.345, df = 3, P=.00). The p-value is 0.009999. The result is significant at $p < 0.01$.

Table 11: Continuous improvement results

	Important				Practiced			
F4:Continuous Improvement	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:Improment coordination	4.22	0.67	0.44	0.63	3.44	0.88	0.78	0.83
Q2:Improvement teams	4.56	0.53	0.28	0.50	2.67	0.50	0.25	0.47
Q3: Quality tools used	4.56	0.73	0.53	0.50	2.89	1.05	1.11	0.99
Q4: Process improvements	4.22	0.97	0.94	0.68	3.00	1.12	1.25	1.05
Average	4.39	0.72	0.55	0.58	3.00	0.89	0.85	0.84

4.3.1.5 Suppliers quality management**Calculated**

Importance chi-square value = 4.238, df = 4, P= 0.375. The p-value is 0.374753. The result is not significant at $p < 0.05$.

Practiced Chi-Square value = 4.138, df = 4, P= 0.39. The p-value is 0.387652. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 9.488, df = 4, P=.049. The p-value is 0.049994. The result is significant at $p < 0.05$

At 1% chi-square value = 13.279, df = 4, P= 0.009. The P-Value is 0.00999. The result is significant at $p < 0.01$

Table 12: Suppliers quality management results

	Important				Practiced			
F5:Supplier Quality Management	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:Quality base for selection	4.44	0.53	0.28	0.50	2.22	0.67	0.44	0.63
Q2:Meet quality specification	4.11	0.93	0.86	0.87	2.33	0.50	0.25	0.47
Q3:Suppliers' quality audits	4.00	1.32	1.75	1.25	1.67	0.87	0.75	0.82
Q4:Supplier relationship	3.89	0.93	0.86	0.87	2.56	0.53	0.28	0.50
Q5:Quality records	4.56	0.73	0.53	0.68	2.78	0.44	0.19	0.42
Average	4.20	0.89	0.86	0.84	2.31	0.60	0.38	0.57

4.3.1.6 Systems and processes

Calculated

Importance chi-square value = 3.155, df = 3, P= 0.37. The p-value is 0.368339. The result is not significant at $p < 0.05$.

Practiced chi-square value = 3.158, df = 3, P= 0.37 . The p-value is 0.3679. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 7.815, df = 3, P=.049. The p-value is 0.049994. The result is significant at $p < 0.05$.

At 1% chi-square value = 11.345, df = 3, P=.00). The p-value is 0.009999. The result is significant at $p < 0.01$.

Table 13: Systems and processes results

	Important				Practiced			
F6:Systems and Processes	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:System procedures	4.56	0.73	0.53	0.68	3.44	0.53	0.28	0.50
Q2:Internal data collection	4.67	0.50	0.25	0.47	3.78	0.44	0.19	0.42
Q3:Feedback system exist	4.56	0.73	0.53	0.68	2.33	1.12	1.25	1.05
Q4:Employees evaluation	4.67	0.50	0.25	0.47	3.11	0.33	0.11	0.31
Average	4.61	0.61	0.39	0.58	3.17	0.60	0.46	0.57

4.3.1.7 Education and training

Calculated

Importance chi-square value = 2.836, df = 3, P= 0.42). The p-value is 0.417608. The result is not significant at $p < 0.05$.

Practiced chi-square value = 3.206, df = 3, P= 0.36. The p-value is 0.360941. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 7.815, df = 3, P=.049. The p-value is 0.049994. The result is significant at $p < 0.05$.

At 1% chi-square value = 11.345, df = 3, P= 0.01. The p-value is 0.009999. The result is significant at $p < 0.01$.

Table 14: Education and training results

	Important				Practiced			
F7:Education and Training	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1:Always update knowledge	4.67	0.71	0.50	0.67	3.44	0.53	0.28	0.50
Q2: On job training	4.56	1.01	1.03	0.96	2.56	0.53	0.28	0.50
Q3: Total quality training	4.56	0.53	0.28	0.50	1.22	0.44	0.19	0.42
Q4:Continous learn	4.78	0.67	0.44	0.63	2.22	0.97	0.94	0.92
Average	4.64	0.73	0.56	0.69	2.36	0.62	0.42	0.58

4.3.1.8 Work environment and culture results

Calculated

Importance chi-square value = 3.184, df = 3, P= 0.36. The p-value is 0.364117. The result is not significant at $p < 0.05$.

Practiced chi-square value = 3.188, df = 3, P= 0.36. The p-value is 0.363538. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 7.815, df = 3, P=.0049. The p-value is 0.049994. The result is significant at $p < 0.05$.

At 1% chi-square value = 11.345, df = 3, P= 0.01. The p-value is 0.009999. The result is significant at $p < 0.01$.

Table 15: Work environment and culture results

	Important				Practiced			
F8:Work Environment and Culture	Mean	SD	Variance	P_SD	Mean	SD	Variance	P_SD
Q1: Good work environment	4.78	0.44	0.19	0.42	2.67	0.71	0.50	0.67
Q2:Positive values	4.67	0.50	0.25	0.47	3.00	0.71	0.50	0.67
Q3:Teamwork practiced	4.67	0.71	0.50	0.67	4.11	0.78	0.61	0.74
Q4: Satisfaction initiatives	4.78	0.44	0.19	0.42	3.44	0.53	0.28	0.50
Average	4.72	0.52	0.28	0.49	3.31	0.68	0.47	0.64

4.3.1.8 Overall questionnaire results

The following were the final questionnaire results:

Table 16: Questionnaire results priority by importance and practice

Elements of QMS	Importance	Practiced
F1: Management Leadership	4.54	3.11
F2: Resource Management	4.44	3.80
F3: Measurement and Feedback	4.47	3.69
F4:Continuous Improvement	4.39	3.00
F5:Supplier Quality Management	4.20	2.31
F6:Systems and Processes	4.53	3.17
F7:Education and Training	4.89	2.36
F8:Work Environment and Culture	4.81	3.31
Overall QMS average value	4.53	3.09

4.3.2 TQM implementation survey results

Calculated

Chi-square value management = 17.43, df = 13, P= 0.18. The p-value is 0.180. The result is not significant at $p < 0.05$.

Chi-square value employee = 16.345, df = 13, P= 0.231. The p-value is 0.231. The result is not significant at $p < 0.05$.

Chi-square value QMS elements = 16.986, df = 13, P= 0.199. The p-value is 0.199. The result is not significant at $p < 0.05$.

Table

At 5% chi-square value = 22.362, df = 3, P=0.05. The p-value is 0.05. The result is not significant at $p < 0.05$.

At 1% chi-square value = 27.688, df = 3, P= 0.01. The p-value is 0.01. The result is significant at $p < 0.01$.

The following were perceived barriers to TQM by employees:

Table 17: Barriers to TQM by employee

Barriers to TQM implimentation employees	Mean	SD
1. Lack of understanding.	3.02	0.74
2. Lack of preparation (No budget, no sponsor).	3.93	0.78
3. Resistance to change (Too busy)	2.40	0.76
4. Lack of vision.	2.97	0.73
5. Lack of top management commitment.	2.11	0.72
6. Lack of customer focus.	2.47	1.03
8. Lack of resources.	2.73	1.10
9. Lack of systems and structures for TQM activities.	2.27	0.70
10. Availability to training.	1.98	0.57
11. Training with no purpose.	3.07	0.97
12. Costly consultancies, training programs.	3.33	0.43
13. Lack of rewards and recognition.	3.85	0.98
14. Lack of effective measurement criteria.	2.81	0.70
15. Lack of evaluation procedures and benchmark indices	3.33	1.12
Avearage per dessignation	3.36	0.81

The following where perceived barriers to TQM by management:

Table 18: Barriers to TQM by management

Barriers to TQM implimentation (managerial employees)	Mean	SD
1. Lack of understanding.	3.02	0.53
2. Lack of preparation (No budget, no sponsor).	3.93	0.88
3. Resistance to change (Too busy)	2.40	0.45
4. Lack of vision.	2.97	0.61
5. Lack of top management commitment.	2.11	0.38
6. Lack of customer focus.	2.47	0.64
8. Lack of resources.	2.73	0.65
9. Lack of systems and structures for TQM activities.	2.27	0.35
10. Availability to training.	1.98	0.27
11. Training with no purpose.	3.07	0.85
12. Costly consultancies, training programs.	3.33	0.87
13. Lack of rewards and recognition.	3.85	0.90
14. Lack of effective measurement criteria.	2.81	0.64
15. Lack of evaluation procedures and benchmark indices	3.33	0.67
Average Score per dessignation	3.36	0.72

The following were the results of barriers to TQM implementation in the ash plant:

Table 19: Barriers to TQM implementation in the ash plant.

Barriers to TQM implimentation (overall avarage)	Mean	SD
1. Lack of understanding.	2.58	0.53
2. Lack of preparation (No budget, no sponsor).	2.68	0.88
3. Resistance to change (Too busy)	2.50	0.45
4. Lack of vision.	2.31	0.61
5. Lack of top management commitment.	2.02	0.38
6. Lack of customer focus.	2.46	0.64
8. Lack of resources.	2.29	0.65
9. Lack of systems and structures for TQM activities.	2.60	0.35
10. Availability to training.	1.95	0.27
11. Training with no purpose.	2.04	0.85
12. Costly consultancies, training programs.	2.52	0.87
13. Lack of rewards and recognition.	2.19	0.90
14. Lack of effective measurement criteria.	2.31	0.64
15. Lack of evaluation procedures and benchmark indices	2.59	0.67
Overall average	2.36	0.72

4.4 Process problems (factorial design)

4.4.1 Three factorial experiments

A factorial experiment was performed to measure main factor effects and interacting (relationships) effects of the three factors at different levels to identify controllable inputs that have the most effects on the output. The controllable variable in the conveyor system identified were conveyor speed, operating hours (mean time between failures) and ash capacity (amount of ash transported). Table 20 below shows the controllable factors to be varied in the experiment.

Table 20: Process controllable factors

Name	Low level	Medium level	High level	Units
Speed (X1)	1	2.5	2.87	m/s
Time (X2)	7	15	24	H
Capacity (X3)	650	1300	2060	T/H

4.4.2 Experimental output data recorded

Controllable process input variables were varied as shown in the table below and the response output recorded. Online real-time process output data (percentage performance and throughput operating hours) was recorded during the experiment period (1 July to 27 July).

Table 21: Experiment recorded data

Run order	Controllable variables	Column 1	Column 2	Performance	Throughput time
	X_1 -speed	X_2 -Time	X_3 - capacity	$Y1(\%)$	$Y2(H)$
1	-1	-1	-1	29.52333333	7.0856
2	1	-1	-1	94.85666667	22.7656
3	-1	1	-1	91.23666667	21.8968
4	1	1	-1	95.62	22.9488
5	-1	-1	1	44.09666667	10.5832
6	1	-1	1	94.57	22.6968
7	-1	1	1	66.57333333	15.9776
8	1	1	1	94.95333333	22.7888
Yields					

Table 21 above, indicates the value of the output plant performance (Y1) and operating hours (y2) which were recorded. The effects calculations were done using the formula:

$$Effects (Y1) = \left(\frac{SumX1 +}{n} \right) - \left(\frac{SumX1 -}{n} \right)$$

N = the number of data point

For performance output (Y1)

$$X1 = \frac{95 + 95 + 44 + 96}{4} - \frac{95 + 91 + 94 + 67}{4} = 95 - 58 = 37$$

For operating hours output (Y2)

$$X1 = \frac{23 + 23 + 23 + 21}{4} - \frac{22 + 23 + 11 + 23}{4} = 8.5$$

Table 22 below shows the factorial design results calculated as above.

Table 22: Factorial design results

	X1 (Speed)	X2 (Time)	X3 (Capacity)	X1X2	X1X3	X2X3	X1X2X2	Y1	Y2
1	-1	-1	-1	1	1	1	-1	30	7
2	1	-1	-1	-1	-1	1	1	95	23
3	-1	1	-1	-1	1	-1	1	91	22
4	1	1	-1	1	-1	-1	-1	95	23
5	-1	-1	1	1	-1	-1	1	44	11
6	1	-1	1	-1	1	-1	-1	94	23
7	-1	1	1	-1	-1	1	-1	67	16
8	1	1	1	1	1	1	1	96	21
Effect (Y1)	37	21.5	-2.5	-20.5	2.5	-9	10	76.5	
Effect (Y2)	8.5	4.5	1	-5.5	0	-3	-2		18.25

Table 23 shows results when time is interacted with capacity by getting the average value of the two numbers.

Table 23: Average values for time and capacity interactions

Column 1	Column 2	Column 3	Column 4	Column 5
Standard	X1 - Speed	X2 - Time	Y1 (Average)	Y2 (Average)
1,2	-1	-1	77.5	15
3,4	1	-1	93	22.5
5,6	-1	1	69	17
7,8	1	1	81.5	18.5

The three largest effects on performance:

$$\text{The sum of squares (SS) or X1} = \text{Number of } \frac{\text{runs}}{4} (\text{effects})^2 = \frac{8}{4} (37)^2 = 2738$$

$$SS(X2) = \frac{8}{4(21.5)^2} = 924.5$$

$$SS(X2) = \frac{8}{4(21.5)^2} = 924.5$$

$$SS(X1X2) = \frac{8}{4} (20.5)^2 = 840.5$$

$$SS_{\text{model}} = SS(X1) + SS(X2) + SS(X1X2) = 2738 + 924.5 + 840.5 = 4503$$

$$SS(\text{Residual}) = \frac{8}{4(-2)^2} + \frac{8}{4(2.5)^2} + (-9)^2 = 2862$$

$$\text{Mean square} = \frac{MS_{\text{model}}}{MS_{\text{residual}}} = \frac{4503}{2862} = 1.57$$

Table 24 below shows the results for analyses of variance for performance

Table 24: Analyses of variance for performance

Source	Sum of squares	DF	Mean squares	F value	Prob > F
SSmodel	4503	3	1501	2.0978	< 0.001
X1	2738	1	2738	3.8267	< 0.001
X2	925.5	1	925.5	1.2935	< 0.001
X1X2	840.5	1	840.5	1.1747	< 0.001
Residual	2862	4	715.5		
Core Total	7365	7			

The three largest effects on operating hours:

$$SS(x1) = \frac{8}{4(8.5)^2} = 134.48$$

$$SS(x2) = \frac{8}{4(4.5)^2} = 2(20.25) = 40.5$$

$$SS(X1X2) = \frac{8}{4(-8.8)^2} = 2(30.25) = 60.5$$

$$SS_{\text{model}} = SS(X1) + SS(X2) + SS(X1X2) = 134.48 + 40.5 + 60.5 = 225.48$$

$$SS_{\text{residual}} = \frac{8}{4(1)^2} + \frac{8}{4(0)^2} + \frac{8}{4}(-3)^2 + \frac{8}{4(-2)^2} = 26$$

Table 25 below shows the results for the analyses of variance for throughput time.

Table 25: Analyses of variance for throughput time

Source	Sum of squares	DF	Mean squares	F value	Prob > F
SSmodel	225.48	3	75.16	11.563	0.001
X1	134.48	1	134.48	134.48	0.001
X2	40.5	1	40.5	40.5	0.001
X1X2	60.5	1	60.5	60.5	0.001
Residual	26	4	6.5		
Core Total	251.48	7			

The factorial model of performance for two factors, each at two levels.

The regression model that was used to represent this process:

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_{12}x_1x_2$$

$$Performance = 76.5 + 18.5X_1 + 10.75 x_2 - 10.25 X_1X_2$$

Using table 11 signs

$$Performance\ 1\ (Standard\ Order) = 76.5 - 18.5 - 10.75 + 10.25 = 37$$

$$Performance\ 2\ (Standard\ Order) = 76.5 + 18.5 - 10.75 + 10.25 = 95.5$$

Table 26 below shows the results of comparison between actual performance and predicted performance with residuals.

Table 26: Comparison between actual performance and predicted performance

Standard order	X1 (Speed)	X2 (Time)	X1X2	Performance actual	Performance predicted	Residual
1	-1	-1	1	30	37	-7
2	1	-1	-1	95	95.5	-0.5
3	-1	1	-1	91	79	12
4	1	1	1	95	95.5	-0.5
5	-1	-1	1	44	37	7
6	1	-1	-1	94	74	20
7	-1	1	-1	67	58.5	8.5
8	1	1	1	96	95.5	0.5

The factorial model of operating hours for two factors, each at two levels

Performance = $18.25 + 4.25X_1 + 2.25X_2 - 2.75X_1X_2$ Using table 12 signs

Performance 1 (standard order) = $18.25 - 4.25 - 2.25 + 2.75 = 16.75$

Performance 2 (Standard order) = $18.25 + 4.25 - 2.25 + 2.75 = 23$

Table 27 below shows results of actual operating hours, predicted operating hours and its residual values.

Table 27: Actual operating hours and predicted operating hours

Standard order	X1 (Speed)	X2 (Time)	X1X2	Operating hours actual	Operating predicted	Residual
1	-1	-1	1	7	16.75	-9.75
2	1	-1	-1	23	23	0
3	-1	1	-1	22	9	13
4	1	1	1	23	22	1
5	-1	-1	1	11	9	2
6	1	-1	-1	23	23	0
7	-1	1	-1	16	13.5	2.5
8	1	1	1	21	22	-1

4.5 Results summary

The brainstorming session results indicate that the control of critical spares is vital as the station is in its midlife and the most originally installed equipment has become obsolete. The budget constraint was also revealed as a contributory since most outages were deferred due to the unavailability of the capital budget to execute predetermined scopes (replacements governed by plant technical plan), which resulted in equipment failing to load (run to failure). The problem with core crew skills was also evident, especially lack of knowledge in specialized equipment which also relates to the service level of the team (skills leaving vs new skills entering section).

The Pareto analysis revealed that poor maintenance practice was leading to high material flow due to high premature failure. This had a significant impact on financial performance, operational performance and technical performance resulting in the stock-holding capacity to be increased if the root causes of failure were not addressed. It was also evident that poor engineering change control (replacement of obsolete spares with new or replacement parts without staff being properly trained) and poor spares procurement quality management (spares defects noticed too late) contributed significantly to the underperformance.

The cause and effect diagram was drawn up to focus on the causes of conveyor unavailability. The main causes focused on, were methods, measurement and machine condition. It was also evident that the environmental conditions in the ash plant contributed significantly to the premature failure of equipment.

Factorial experiments focused on analysing the ash transportation process by comparing current performance levels with design requirements or desired performance. It became evident that the ash process results indicated that the ash plant in its current state was out of statistical control and not capable of delivering the process requirements. This can be seen by the amount of ash backlog that the system accumulated during the duration of the experiment, also taking into account that when the experiment was conducted, only five units were on load because Unit One was on general overhaul. This means that 17% of the ash generated by one unit was not part of the experiment and if the unit was running, the ash backlog would also increase by almost 17%.

4.4.5 Verification and validation

A Pareto analysis was done to identify whether a minority of causes were leading to the majority of problems. Data analysis was done on ten major events to determine the severity of quality problems in the ash plant. It was found that quality problems contributed to all the events. The research results were verified by calculations including standard deviation, mean, analysis of variance, chi-square tests and Cronbach's alpha reliability coefficient. A pilot survey was also done to verify the survey questionnaire. Validation was done by doing a cost analysis which indicated that the cost of material rose by 69% in the last four years. Suggestions were made on how QMS in the ash plant could be improved. Interviews were conducted with the operating and engineering managers. As a recommendation from the meeting, an additional questionnaire about the implementation of TQM was included and sent with the original questionnaire.

4.4.5 Critical analysis

The brainstorming results were benchmarked/compared to other research results. According to a study titled the title "Implementation of ISO 9000 system in manufacturing" by Asiri (2000:33), the most common problem with most maintenance departments is the availability of correct spares and the know-how (skills) to do critical work. This corresponds with the findings of the brainstorming session.

The cause and effect data was collected and a diagram was finalised. The factors that were identified as major causes were materials, methods and measurements. The outcome was benchmarked to other research that had been undertaken in the past. A study by Asiri (2000:17), titled "Implementation of ISO 9000 system in manufacturing", confirmed that due to changes in technology, new spares require specialised knowledge and therefore requires employees that are not only experienced, but also have the necessary knowledge to install it correctly the first time. The study also confirmed that improper equipment installation contributes around 25% of equipment failures.

Pareto analyses confirmed that there were poor maintenance practices and if poor engineering controls were eliminated, 80% of the technical problems would be solved. This was benchmarked with the study titled "Implementing a QMS at statistics Sweden", by Lisai (2007:21), which confirmed that in companies that have operated more than 20 years, the common problems included engineering change management and maintaining equipment to the desired standard. It was highlighted that this is mostly due to job hopping by employees and a lack of willingness by organisations to invest in their employees' training (in Sweden).

The survey picked up that the overall score confirmed that all elements of the quality system are important, but the practiced part trailed very low. The confirmation was benchmarking with ISO 900 approved companies. The study by Asiri (2000:17), has confirmed that ISO 9000 in itself cannot resolve some of the business challenges on its own. It requires other management systems support to be effective, which seems to be in line based on our findings.

The factorial results showed that the ash process is out of statistical control because from time to time, overloading was recorded, but could not be attributed to either stoppages or bad coal quality. Dhillon (1999:81) confirms that aging equipment wear quickly especially when operating above maximum limit.

Chapter 5: Discussion and Interpretation

This chapter discusses and interprets the brainstorming, cause and effect diagram, survey and three factorial results reported in Chapter 4 using the relevant theory presented in Chapter 2 and the research design in Chapter 3. This was done with the objective of answering the research question in Chapter 1 by generating new knowledge that can be used to resolve the problem.

5.1 Introduction

This chapter presents the analysis of the key research findings that have emerged from the research process. The results were analysed under each research method section and meaningful conclusions were drawn from the information. Graphs and charts were used in this chapter to easily interpret data presented in Chapter 4, by revealing patterns that are relevant to the research findings, ensuring that conclusions are drawn from well informed and relevant information.

5.2 Technical failure causes analysis

5.2.1 Brainstorming findings

The brainstorming session helped the team to break the status quo generating new original solutions to ash plant problems. Benefits achieved include a wide range of options to consider, allowing team members to raise any ideas that came to mind and thus also providing input to other tools, such as the cause and effect diagram and Pareto analysis. Figure 18 below explains the major findings from the brainstorming session.

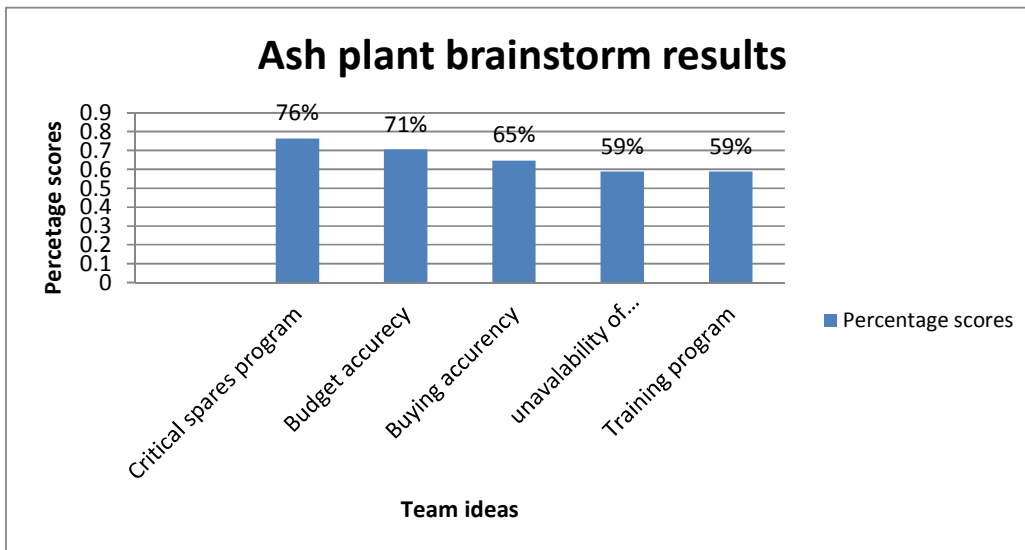


Figure 18: Ash brainstorming findings

Key findings as summarised above are:

1. 76% of the team members agreed that ash plant spares needed to be revised and reclassified according to their impact (critical or operational) on the business.
2. 71% of the team members agreed that the current budget was not sufficient to run the section and needed to be revised so that more accurate material buying could be attained.
3. 65% of the team members indicated that the buying accuracy was a problem because it takes a long time to receive new materials, and the wrong materials are still delivered.
4. 59% of the team members indicated that unavailability of specifications contributed significantly to spares quality management and unavailability.
5. 59% of team members indicated that a lack of task specific training and skills contributed to the problem.

5.2.2 Cause and effect diagram

Cause and effect diagram was useful to identify known possible causes of quality problems in ash conveyors or lack of quality. Some of the benefits this tool produced were determining root causes using a structured approach, utilising group knowledge of the process, easy to follow format of cause and effect relationship, indicate possible causes of variation in the process and

also identify were data pertaining quality problems can be collected for further study. The figure 19 below indicated that machine conditions (maintainability) and material used (quality of spares) were substantial issues.

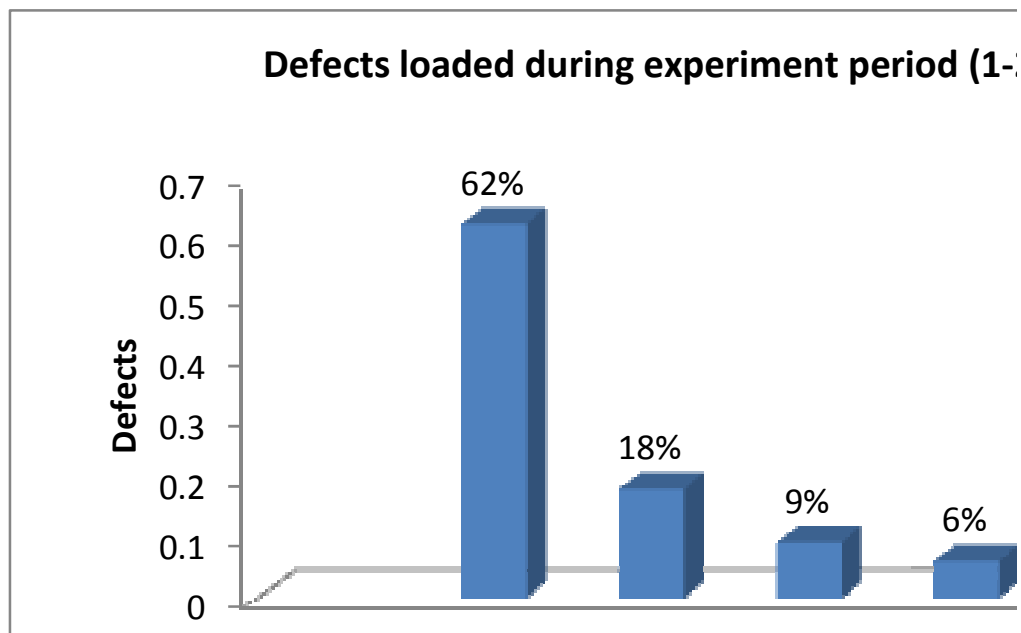


Figure 19: Cause and effect diagram results

The major findings of the cause and effect diagram were:

1. 62% of conveyor failures were machine maintenance related, mostly idlers, conveyor belts (rubber material), bearings and coupling failures. This also constituted 81% of defects/notifications generated in July 2015.
2. 18% of conveyor failures relate to spare management. This was a combination of unavailability and poor quality of spares. This also relates to the procurement policy of using price to determine suppliers, which resulted in more technical problems (policy constraint)

The Pareto chart below in Figure 20, shows the percentage defects/notifications loaded in the ash plant in July 2015 per material/part/spare.

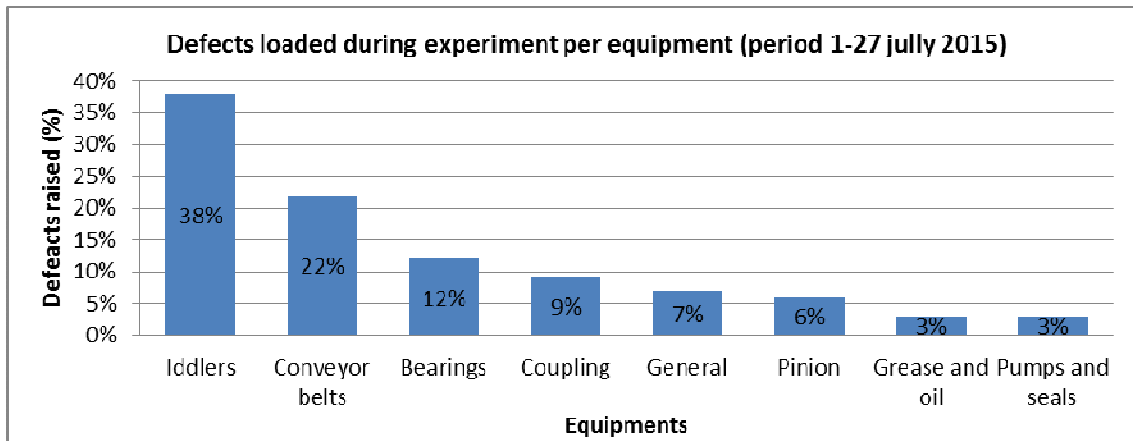


Figure 20: July defects per equipment

5.2.3 Pareto analysis

The purpose of using a Pareto chart was to break the research sub-problem into smaller pieces in order to identify the main contributors. This helps to identify where to maximise efforts utilising minimum resources available in order to maximise achievements. A Pareto chart was used to identify which problems to study and which causes of the problem should be addressed first for the solution to be the most effective. Causes such as resource unavailability, lack of training and normal wear and tear were identified as being less important to the extent that their effect was negligible. The Pareto analysis findings were:

1. High material flow (as a result of high equipment/parts usage) rendered current stock levels to be insignificant. This is as a result of maintenance backlog. 50% of defects/notifications in July related to equipment or parts failure.
2. Poor engineering controls. The plant's uncontrolled changes resulted in an unbalanced system due to a lack of proper engineering change management. This resulted in long production downtimes due to fault-finding that took too long.

The Pareto analysis indicated that if these two causes were addressed, 80% of the conveyor system problems would be solved. This analysis also provided scores to inform the severity of the problems at hand. Figure 21 below shows the Pareto chart indicating the results of the analyses.

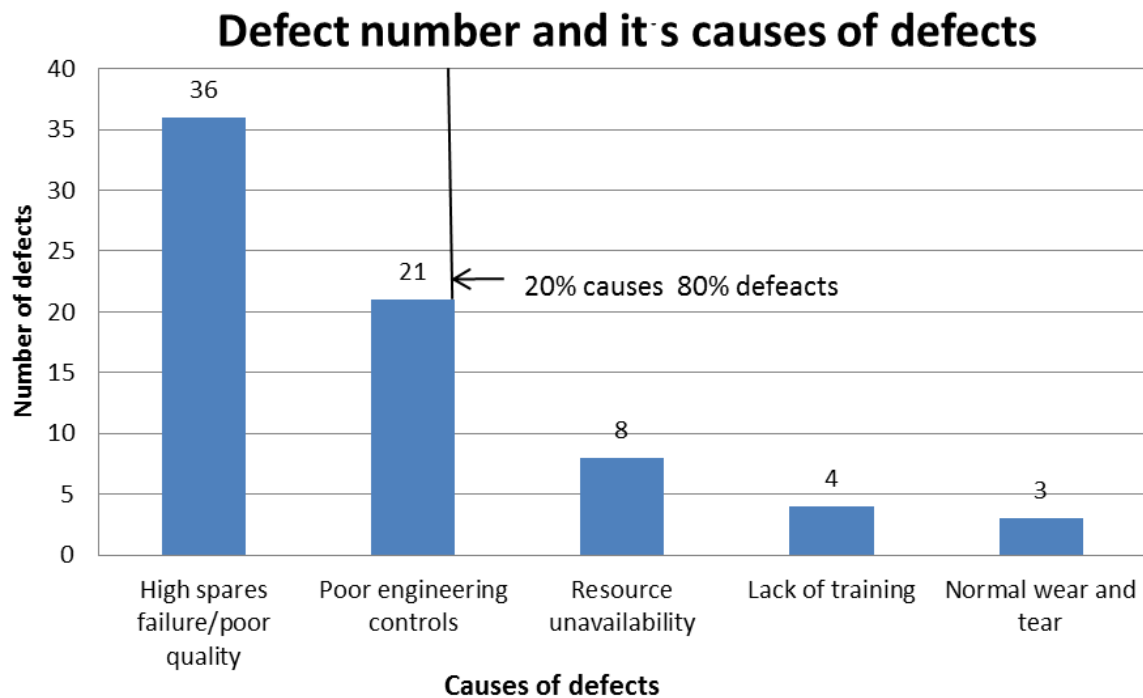


Figure 21: Number of defects vs causes of defects

5.3 Survey findings (management system analyses)

The survey participants were asked to rate the level of importance and level of practice of the eight elements of QMS. These were:

3. The level of perceived importance of the QMS elements on a five point Likert scale ranging from 1 = not important at all, 2 = not important, 3 = neutral important, 4 = important and 5 = very important.
4. The extent or degree of practice the particular elements receive in a day to day ash plant operation. This was also ranked on a Likert scale ranging from 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high.

The mean and standard deviation values were calculated for each QMS element to determine the elements of priority from high to low so that attention could be given to a highest element priority first, then to the next most important priority. This is based on the theory of constraint (TOC) that addressing a lower priority element before addressing the higher priority elements can be a wasteful exercise

Table 28 below shows the priority by importance (mean values), practice (mean values) and standard deviation. This summary was achieved by determining the mean and standard deviation values per QMS element.

Table 28: QMS elements based on perceived importance, practice and standard deviation

Priority	Importance	Practiced	SD
1	F7: Education and Training	F5: Supplier Quality Management	F7: Education and Training
2	F8: Work Environment and Culture	F7: Education and Training	F5: Supplier Quality Management
3	F1: Management Leadership	F4: Continuous Improvement	F8: Work Environment and Culture
4	F6: Systems and Processes	F1: Management Leadership	F1: Management Leadership
5	F3: Measurement and Feedback	F6: Systems and Processes	F4: Continuous Improvement
6	F2: Resource Management	F8: Work Environment and Culture	F6: Systems and Processes
7	F4: Continuous Improvement	F3: Measurement and Feedback	F3: Measurement and Feedback
8	F5: Supplier Quality Management	F2: Resource Management	F2: Resource Management

Figure 22 below shows how each QMS element has performed using a Likert scale.

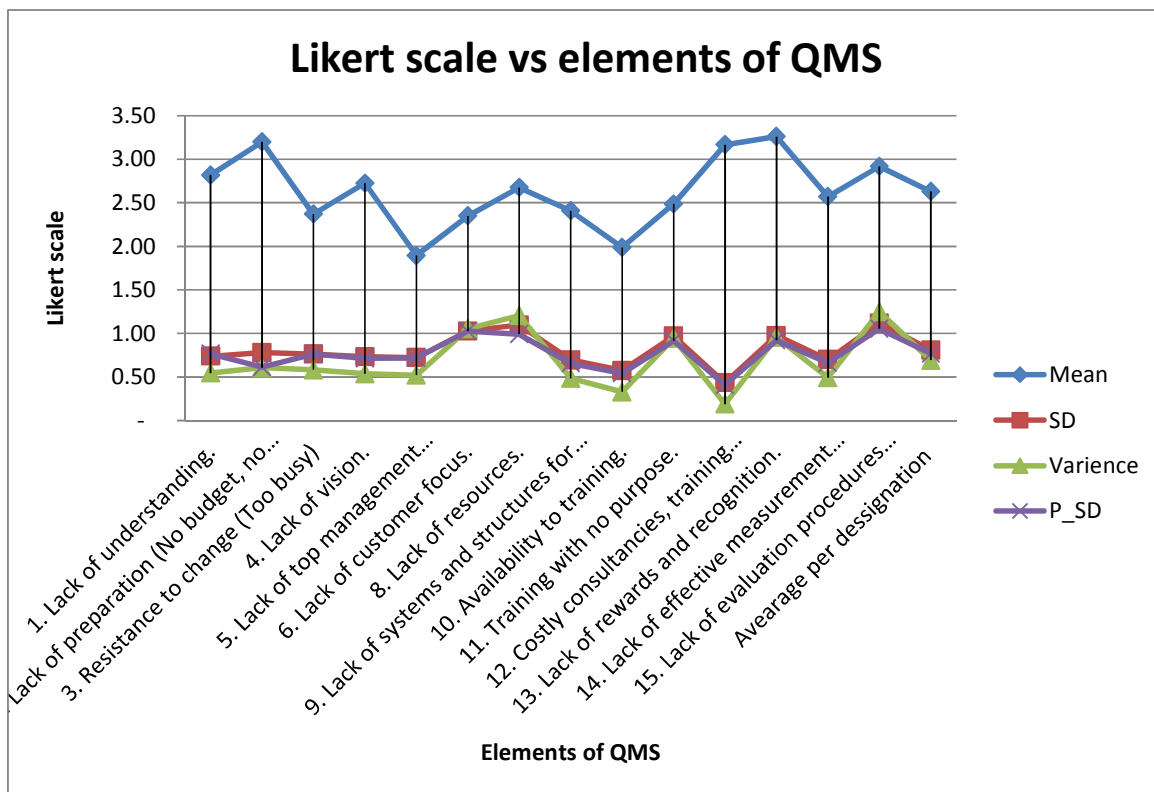


Figure 22: QMS elements performance measured by using a Likert scale

The final survey priority list of QMS elements was derived from the total score which included importance, practiced and deviation per QMS element using a Likert scale. Table 29 below shows the final QMS elements priority list as part of the survey findings:

Table 29: Final QMS elements priority

Priority	QMS elements
1	F5: Supplier Quality Management
2	F7: Education and Training
3	F4: Continuous Improvement
4	F1: Management Leadership
5	F6: Systems and Processes
6	F8: Work Environment and Culture
7	F3: Measurement and Feedback
8	F2: Resource Management

The table above indicates that more attention has to be given to priority one in sequence up to priority 8 because all were measured to be less than 4 (important and high) using the Likert scale.

5.4 Factorial design (process problems analysis)

5.4.1 Input variability and its effects on the output

Figure 23 below shows the effect on performance from high to low:

1. Conveyor speed (X1)
2. Conveyor operating time (X2)
3. Interaction effect between conveyor speed (X1) and conveyor operating time (X2)
4. Interaction effect between conveyor speed (X1), conveyor operating time (X2) and capacity (load in tons).

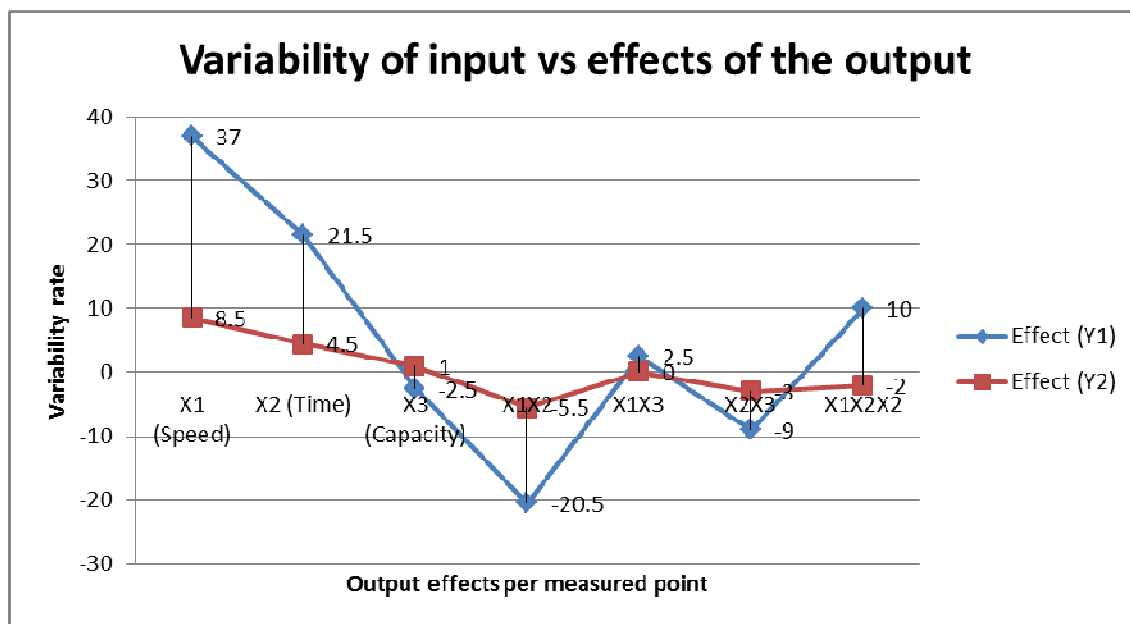


Figure 23: Input variability rate vs effects on the output

From Figure 23 above, it can be seen that throughput time is mainly effected by:

1. Conveyor speed (X1)
2. Interaction effect between conveyor speed (X1) and conveyor operating time (X2)
3. Conveyor operating time (X2)
4. Interaction conveyor operating time (X2) and capacity (X3)
5. Interaction effect between conveyor speed (X1), conveyor operating time (X2) and capacity (X3)

5.4.2 Half normal plots for effects and its Pareto chart

Before plotting the effects, it helps to convert them into absolute values in order to ensure the scale becomes more sensitive to detect significant outcome. The absolute value is accommodated by half normal which is based on a positive half of a full normal curve.

As shown in Figure 24 below, the biggest three effects fall out on the tail of the normal curve to the right. These three effects are significant (X1, X2, X1X2) or most likely significant. We also observe a big gap before the next lowest effect. The four trivial effects (X3, X1X3, X2X3, X1X2X3) closer to zero will be used as an estimate for error in the ANOVA.

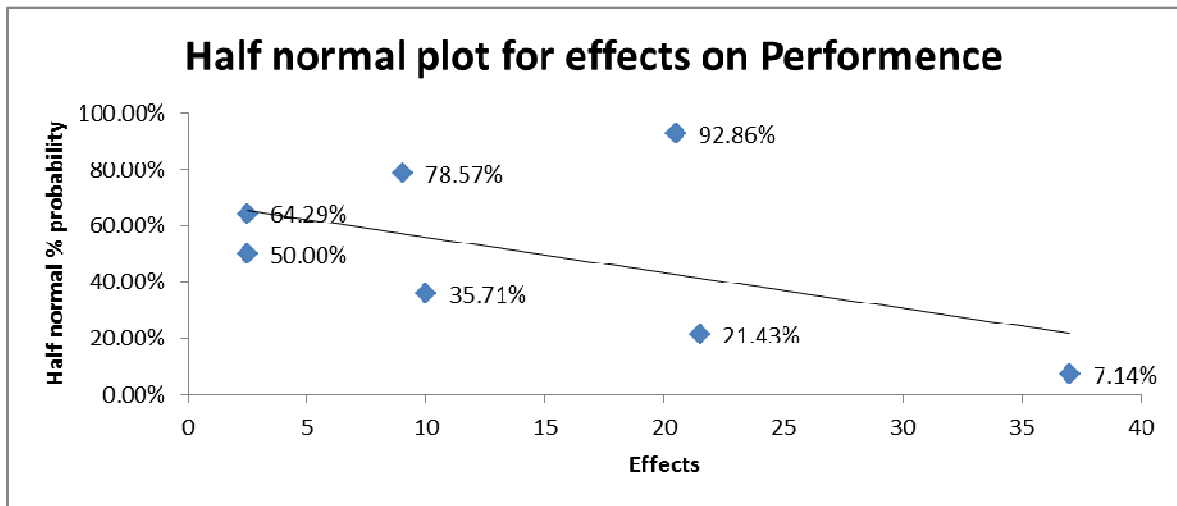


Figure 24: Half normal plot for effects on performance

The Pareto chart in Figure 25 Shows a simple view of relative effects indicated by the

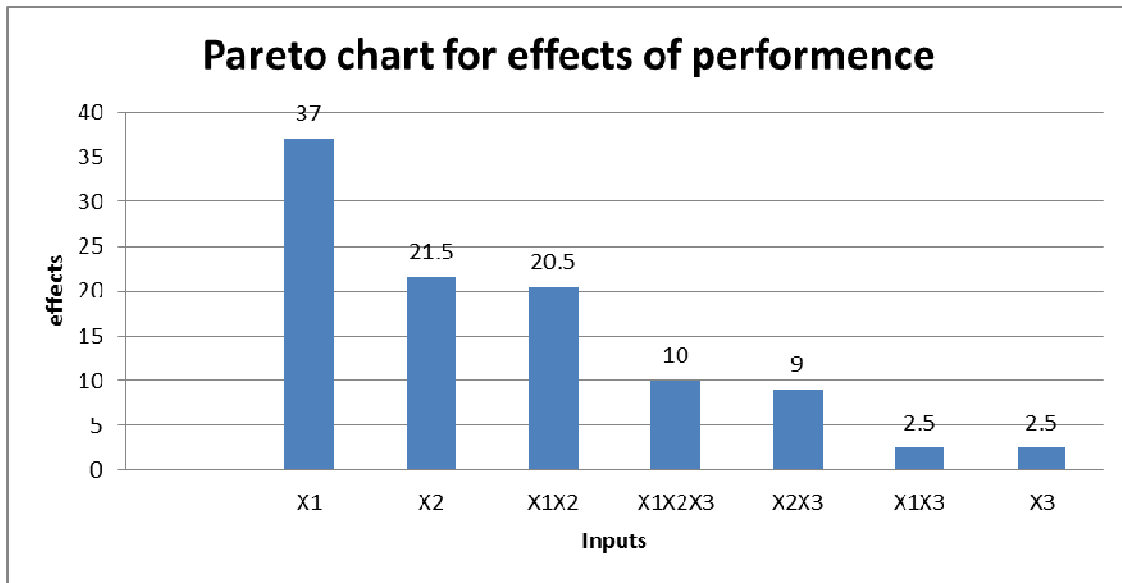


Figure 25: Pareto chart for effects on performance

Figure 26 below, shows that two of the effects fall near zero (X3, X1X3), these effects only vary due to normal causes or may be due to the experiment marking it as insignificant. The effects of X1, X2 and X1X2 are bigger compared to other effects and are considered significant. These factors should be investigated to establish how they interact to affect the response of throughput time.

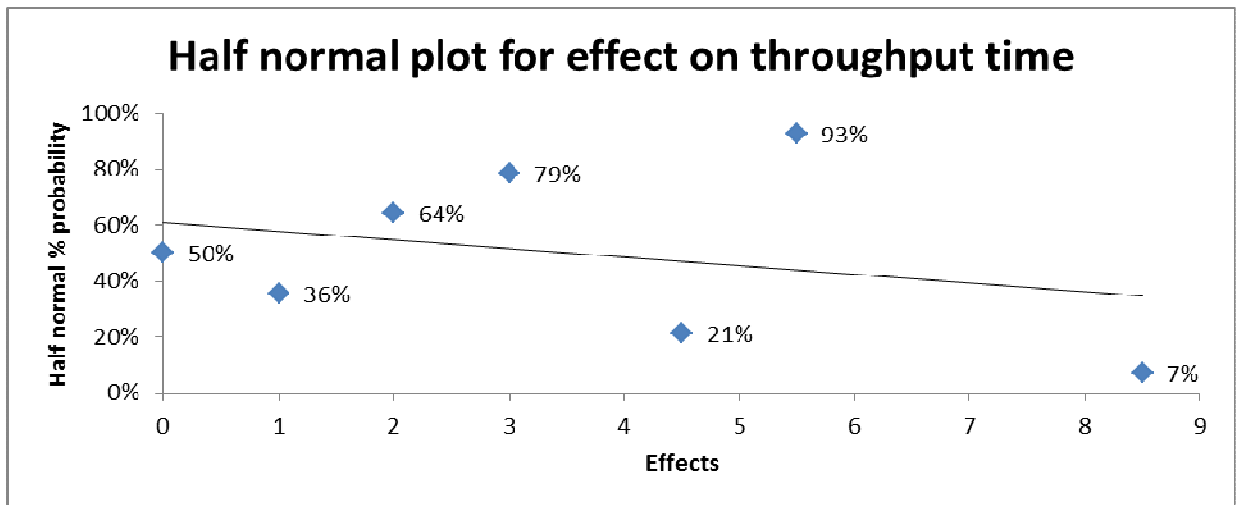


Figure 26: Half normal plots for effects in throughput time

The Pareto chart in Figure 27 below shows that the impact of X1, X1X2 and X2 on the left is the vital few (significant) and the rest on the right trivial many (insignificant).

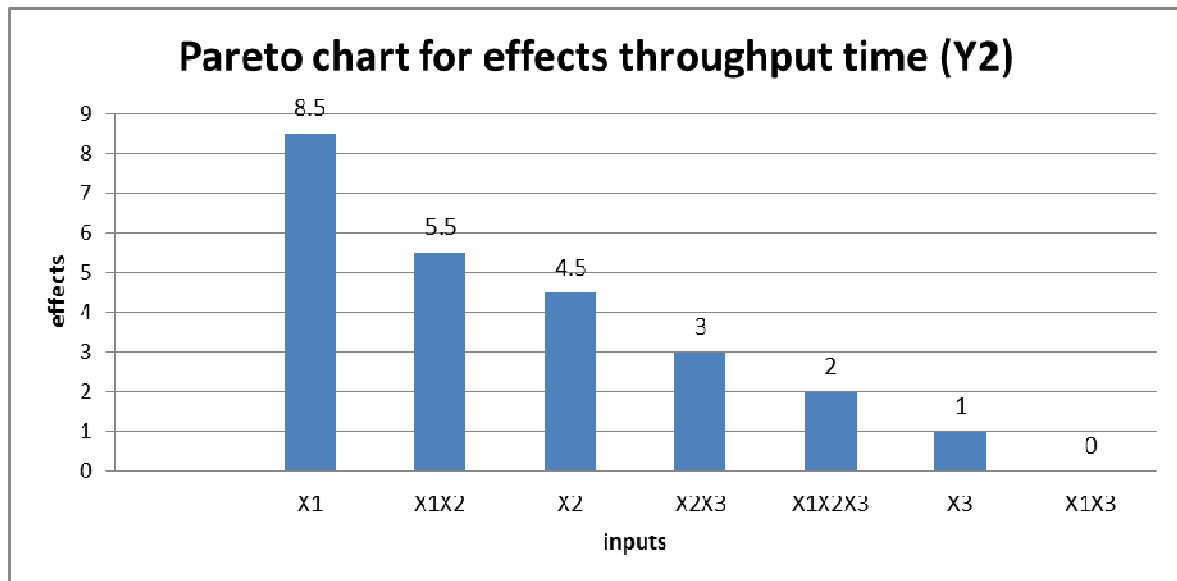


Figure 27: Pareto chart for effects on throughput time

5.4.3 Analysis of variance (ANOVA)

The factorial experiment results above show that the ash conveyor system is also out of statistical control and incapable of delivering the process requirements. To verify and validate the results above, the statistical validation was done by performing an ANOVA. If the residual is normally distributed, it will fall in line. In this case deviations from the linear pattern are present. This is a completely non-linear pattern taking almost an "S" shape and requires a response transformation to be done. Figure 28 below shows the normal plot of performance residual.

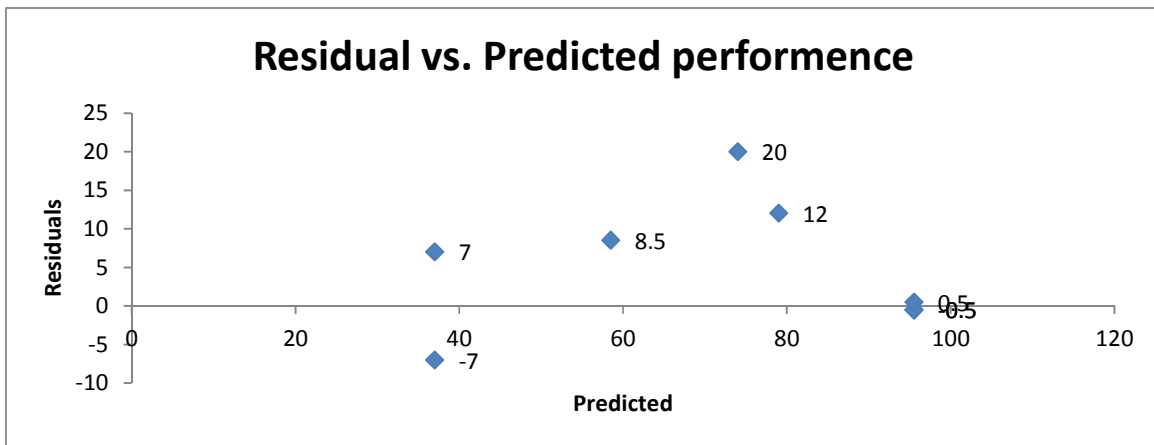


Figure 28: Residual vs predicted performance

Figure 29 below shows the normal plot of throughput time residual.

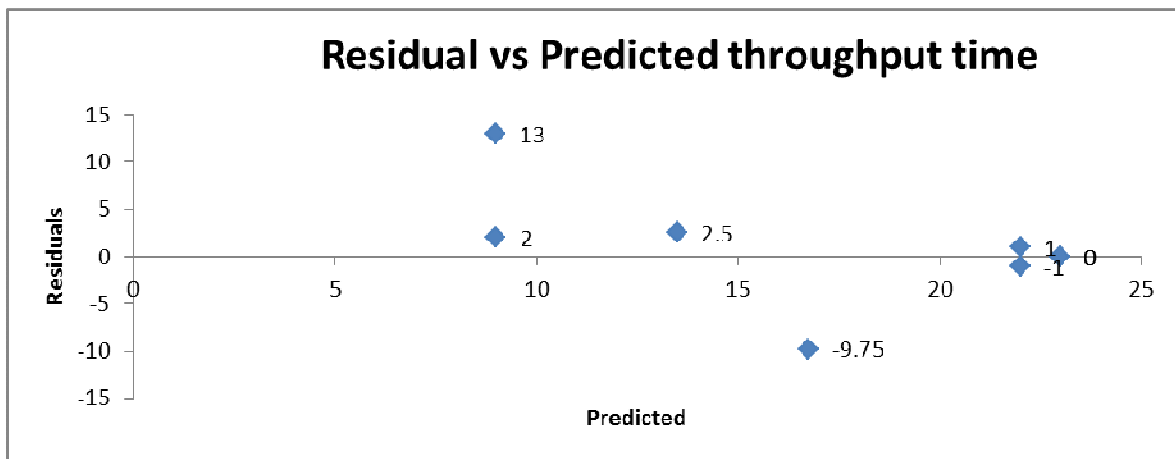


Figure 29: Residual vs predicted throughput time

5.4.4 Three factorial findings

The following are the findings from the factorial experiment:

1. The ash transportation process is out of statistical control (presence of special causes of variation) hence it is incapable of delivering the desired results. This was also caused by huge variations in loading conditions which mostly occurred when the plant was standing and ash backlog accumulated.

2. It was evident that the percentage ash plant performance (Y1) was more affected by: firstly, speed (X1); secondly, operating hours (X2); thirdly, interaction between speed and operating hours (X1x2); fourthly, the interaction between speed, operating hours and loading capacity (X1X2X3). Speed and operating hours need to be maximised at all times to maximise plant efficiency.
3. It was evident that that the throughput time (Y2) was more affected by: speed (x1); secondly interaction between speed and operating hours (x1x2); thirdly, operating hours (X2); fourthly, interaction between operating hours and loading capacity (x2x3); and fourthly interaction between speed, operating hours and loading capacity (x1x2x3).
4. Poor quality coal with high ash content overloaded the conveyor system for short periods (bad batch) of time causing more stress, wear and tear, which resulted in failure of the weakest link in line with the theory of constraint, namely “a chain is as weak as its weakest link”. Managing supplier quality was continuously important for every process.

5.5 Critical analysis

All findings conform to what was verified and validated in Chapter 4. In this chapter, measuring instruments were verified against the research results to assess the possibility of any measurement error, comparing interpretation using the theory in Chapter 2. It was evident that the instrument delivers as they were intended to during the research design.

Chapter 6: Conclusions and Recommendations

This chapter presents a summary and the conclusions drawn from the research. The first section provides an overview of the study, the second section provides the conclusions, the third section presents the recommended solution, and the fourth section makes recommendations for future studies on this topic.

6.1 Introduction

Improving continuously is an important element in a successful QMS. Effectiveness and efficiency of QMS implementation is important for improving performance of any organisation. This study was carried out to investigate the poor performance of the ash plant conveyor system at Eskom Lethabo Power Station to identify contributing factors to prioritise the major factors rather than the minor factors. The research design focused on technical causes, process causes and management system causes as barriers to the ash plant conveyor system's performance.

6.2 Overview of the study

Brainstorming, a cause and effect diagram and Pareto analyses were conducted to investigate the technical part of the problem. Data was collected from Eskom's database for analysis. A questionnaire was developed as an instrument to investigate the management system part of the problem based on an extensive review of literature and test instruments previously used in other studies. The questionnaire was revised for technical and content validity by the North West University's statistical department experts and two QMS experts responsible for the ISO 9001 certification work team. The test instrument was modified based on suggestions, clarifications and recommendations.

A pilot test was performed to verify the absence of errors. 40% of the population was targeted to complete the survey. Questionnaires were sent with a cover letter explaining the objectives of the survey to all participants. Follow-up calls were made to participants to ensure a high response rate. Data was interpreted using several statistical methods. Research results were compared to other research findings of QMS conducted in various fields of study.

The factorial experiment was setup and carried out in July 2015. The ANOVA calculations were performed to verify and validate the results obtained from the experiment. The results were also compared with three other factorial experiments carried out by other researchers in the past.

6.3 Conclusion

1. In spite of Eskom Lethabo being an ISO 9001 certified station, there is a serious non-compliance regarding the eight elements of QMS (ISO 9001).
2. Lack of a proper ISO 9001 plan for the section to comply with the requirements of the system. The cost of implementing the system and consultants' fees may be a contributing reason for the ash plant not fully adopting the system.
3. Lack of clear vision regarding quality management in the ash plant resulted in objectives that weren't specific, measurable, attainable, realistic or time bound (SMART). ISO 9001 certified companies must continuously measure, collect, record and analyse data for continuous improvement.
4. The critical factor of successful implementation and operation of any management system is the involvement of competent people during implementation and operation. This requires quality training and awareness for everyone from middle management to employee at the floor.
5. The service/support department plays a significant role in the success of the QMS. Policy problems of not aligning procurement to the requirements of ISO 9001 have resulted in major quality problems from suppliers.
6. One parameter that is operating outside the process (loading conditions) requirements can cause more damage to the rest of the system if not detected in time.

6.4 Recommend solution

It is recommended that the Lethabo Ash Plant adopts the second step (planning phase) of the TQM implementation process flow, as well as to review the effectiveness of the first phase (which is covered by the requirements of the ISO 9000 QMS). This will ensure that problems relating to technical requirements (operational), process requirements, environmental conditions and management systems are strategically addressed. This approach is actually addressing ISO 9000 requirements by implementing stage one in the TQM (step 1 to 12) implementation process (preparatory phase), which will provide more results. The only major change will be the

implementation of stage two of the TQM planning phase (Steps 12 to 15 of the implementation stage).

6.4.1 Ensure compliance with elements of the QMS (ISO 9001)

The QMS must be continuously evaluated for its effectiveness against the objectives (elements of QMS). The evaluation of the effectiveness of the QMS will be carried out in four stages:

- Performance assessment in functioning level – evaluate processes, efficiency of the process criteria , expenses of quality and effectiveness of quality.
- Quality-centred assessment of the ash plant – evaluate quality culture and the requirements of ISO 9001.
- The principles of management for sustainable success – evaluate the management of financial flows, development of staff proficiency, risk management and the evaluation of the work environment.
- Generalised index – focus on all aspects of the QMS.

Figure 30 below shows an integrated process approach to the QMS model used to improve conveyor system performance. This integrated approach will ensure that when decisions are made in one section or department, all stakeholders are consulted to influence the decisions so that all negative effects can be discussed and mitigating factors put in place timely (holistic decision making). This integrated approach also ensures that all processes that control certain outcomes (procedure, regulations etc.) form part of the decision-making process, strengthening the accuracy of management decision making and the availability of information to all workers.

The procedures of this Quality management system are shown on figure 30 (process activity). For every task performed in the ash plant , both management and employees will know what activity should be performed? , Why should it be performed?, who should perform it?, where should it be performed?, when should it be performed?, and how should it be performed. This procedure addresses all factors that constitute quality problems in the ash plant

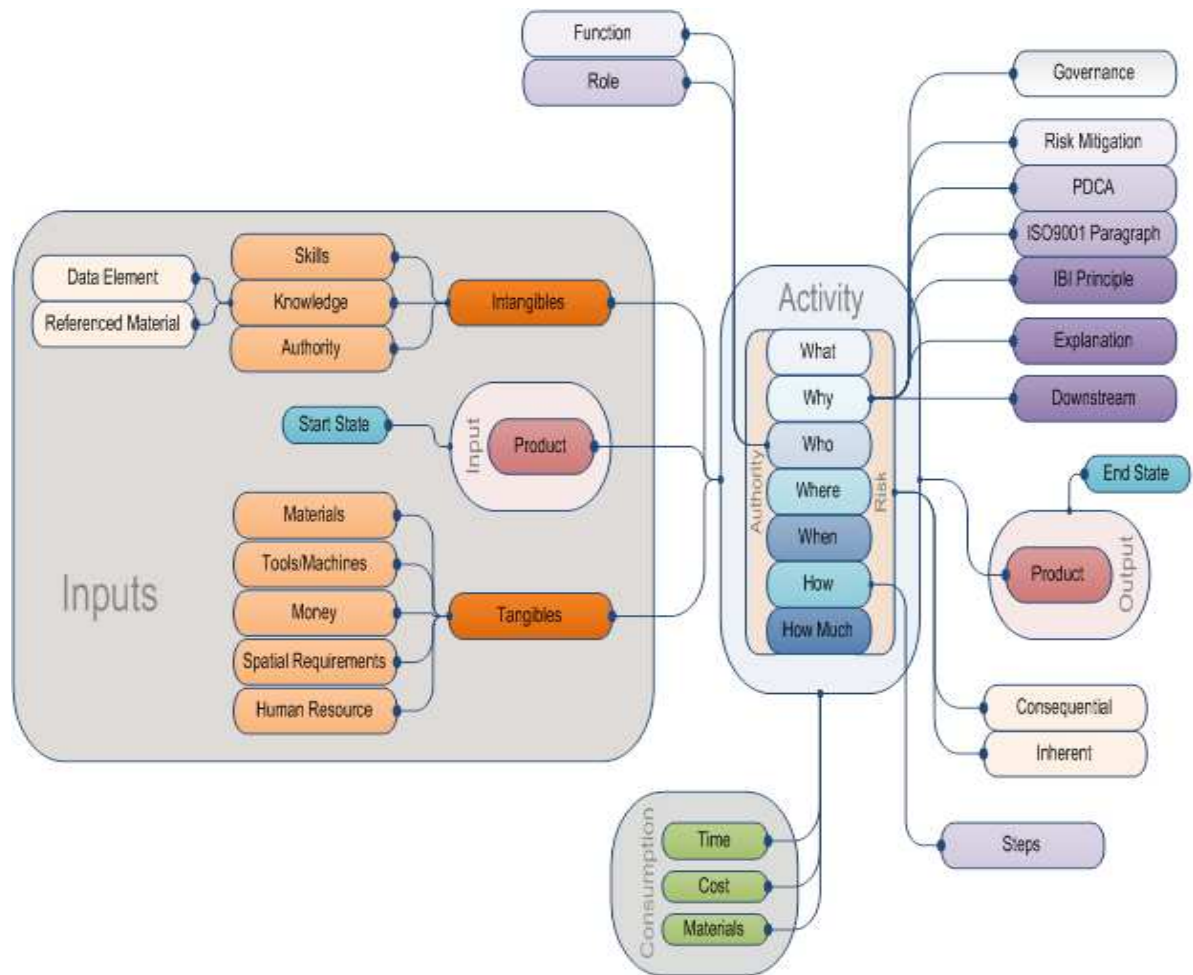


Figure 30: QMS model driving compliance to ISO 9000 and TQM (Foster, 2010)

The QMS model will ensure that the ash plant complies with all quality standards leading to overall performance improvement by:

- Defining the objective of each process identifying all requirements (specific outputs and targets). This will help all employees to understand key outputs and their impact on the overall performance of the conveyor system.
- Critically reviewing processes and ensuring that they are as simple as possible and focusing only on what the process wants to achieve.
- Developing process documents (operating manual, work instructions and procedures) guiding employees exactly what needs to be done so those requirements are achieved?
- Training all employees involved so that they understand all documents that govern their work outputs (identifying all training required for each function).
- Identifying all process key performance indicators by critically identifying all inputs and outputs required to produce quality results.
- Continuous results measurement to ensure process optimisation is performed.

- Ensuring that process owners are held accountable for the process performance
- Developing a process that continuously evaluates applicable quality standards observing possible changes and opportunity for improvement.

6.3.2 Step 12: Plan and implement the plan-do-check-adjust approach

Careful planning and efficient management of the implementation are vital to the success of any QMS project. During this stage, a steering committee starts planning the implementation of total quality. This step continues throughout, during and after TQM is implemented because all information provides feedback to accommodate, correct, adjust and so on. Depending on how the system is working, this stage generates many sub-projects and teams to address any emergent issue. This part is viewed as the heart of TQM which guarantees it to be successful in any application:

1. Plan – identify requirements
2. Do – execute according to requirements
3. Check – evaluate if requirement are meet
4. Adjust – determine corrective of preventative action to be implemented to effect the solution

6.3.3 Step 13: Identify projects

Total quality projects must be selected and carried out based on the priorities identified by the survey results (e.g. the spares project first, followed by the training project). The project team must be open for suggestions to accommodate different views. The following steps must be considered when developing a project plan:

- identify project tasks
- define milestone
- establish timelines
- develop a budget
- assign resources, and
- develop a strategy for progress monitoring.

The following projects were identified:

Table 7: Implementation plan

	Projects	Department responsible	Cost	Duration	Responsible person
1	Development of specifications (Material, spares)	Engineering	R 158 940	2 years	Johan Brink
2	Development of procedures	Engineering	R 138 146	2 years	Johan Brink
3	Development of work instruction	Maintenance	R 121 236	2 years	Siphiwe Mlotshwa
4	Development of QCP/ITP	Maintenance	R 159 734	1 year	Siphiwe Mlotshwa
5	Develop a training matrix for staff	Human resources	R 382 423	1 year	Rodney Lubisi
6	Review all spares requirements	Materials management	R 1 000 000	6 month	Jacob Mosehle
7	Review and prequalify all vendors	Procurement	R 210 456	1 year	Ceলেলwa Mগijima
8	Develop soul source for original equipment manufacturer	Procurement	R 30 000	1 year	Ceলেলwa Mগijima
9	Develop supply contract with vendors	Procurement	R 100 000	2 years	Ceলেলwa Mগijima
10	Documentation and records (drawing etc)	Work management	R 102 563	2 years	Thabane Fihlela
		Total	R 2 244 558		

6.3.4 Step 14: Establish team composition

At this stage, different multi-disciplinary teams are selected based on their strengths. Before the team is assembled, strengths, weakness, opportunities and threats must be identified for project teams so that the best candidates are presented.

6.3.5 Step 15: Provide team training

All teams doing QMS development work must be trained covering all the basics of total quality and tools appropriate for the project. Training can be either internal or external.

5.4 Final research verification and validation

The original research objectives were verified and validated to ensure that the suggested system would be fit for the purposes below:

1. First objective: Identify the gaps between management systems in the ash plant compared to the requirements of ISO 9000 and TQM. The objective was achieved, the questionnaire highlighted all gaps in the current QMS against the requirements of TQM and ISO 9000. Mean values averaged at 3,2 out of five with no element that has achieved 4 or higher.
2. Second objective: Analyse the process parameters to verify whether the plant is operating within the design requirements and that it is capable to deliver the desired results. The

factorial experiment identified that the process was out of statistical control. Proper conveyor loading was identified as the root cause of conveyor spillages and conveyor belt misalignment.

3. Third objective: Investigate how quality processes can be used to ensure continuous improvement of ash plant performance. The three research methods proved that the integrated QMS was required to manage all requirements centrally so that a balanced system could be maintained (not improving quality objectives on the cost of another (e.g. improving performance by sacrificing reliability)).
4. Fourth objective: Integrate quality processes to ensure that all functions performed meet the needs for which they were carried out. This objective was achieved by integrating ISO 9000 and TQM to ensure that the quality system must address technical, administrative, process and systems problems.
5. Fifth objective: Ensure that quality is built into all sub-processes so that preventative and corrective actions can be applied timely when necessary. The Integrated QMS model was created to develop standard work procedure for any work performed in the station. The model requires procedure and work instructions to be developed for any task to be performed in the ash plant. The model also facilitates communication and ensures that the correct tools are bought. (Refer to appendix 1:quality work elements)

5.5 Critical analysis

According to Deming (2013:238), most companies that embrace total quality find it very difficult to begin their total quality journey. It has been proved in the Japanese and American car manufacturing sectors that the ISO 9000 projects can be used as an entrance to total quality. This was confirmed by other quality guru's like Juran and Crosby.

Goetsch and Davis (2013:53), agree that total quality values guide employees' and organisations' behaviour. This emphasises the while importance of knowledge and skills, they do no guarantee results on their own, because individual employees and organisations as a whole will apply their knowledge and skills to what they value and what they believe are important. Values lead to ethical behaviour including fairness, integrity, dependability, honesty and truthfulness. This encourages a working environment that involves values, empowers, and nurture people, not only holding employees accountable but giving them support and providing them with resources to perform their responsibilities.

Bibliography

Arnold, J.R., Chapman, S.N & Clive, L.M. 2008. Introduction to materials management .6th ed. New Jersey: Prentice-Hall.

Blanchard, B.S., Verma, D., & Peterson, E.L. 1995. Maintainability. New York: John Wiley & Sons.

Baily, P. & Farmer, D. 1990. Purchasing principles and management. 6th ed. United Kingdom: Pitman Publishing.

Bertels, T. 2003. Six sigma leadership handbook. New Jersey: John Wiley and Sons.

Cali, J.F. 1993. TQM for purchasing management. United States of America: McGraw-Hill inc.

Crosby, P.B. 1979. Quality is free. New York: New American Library.

Crotty, M. 1998. The foundations of *social* march: Meaning and perspective in the research process. London: Sage.

Dhillon , B.S. 2002. Engineering maintenance: a modern approach. United States of America: Press LLC.

Dhillon, B.S. 1999. Engineering maintainability. Houston, Texas: Gulf Publishing Co

Dorf, R.C.1999. Technology management handbook. Boca Raton, Florida: CRC Press.

Detoro, I. 1995. The 10 Pitfalls of benchmarking, Quality Progress, January, pp.61-63.

Donovan, R.M. 1995. Improving manufacturing cycle time, Quality Digest, June, pp. 51-53.

Evans, J.R. & Lindsay, W.M. 2014. Managing for quality and performance excellence. 9th ed. United States of America, New Jersey: Cengage Learning Inc.

Farrel, P.V. 1981. Purchasing principles and application.6th ed. United States of America: Prentice Hall.

Foster, S.T. 2010. Managing quality integrating the supply chain. 4th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Goldratt, E.L. 1992. The goal. A process of ongoing improvement. 2nd ed: Pretoria: Creda Communications

Goetsch, D.L. & Davis, S.B. 2013. Quality management for organisational excellency. 7th ed. United States of America: Pearson Prentice Hall.

Heinrits, S.F., Farrel, P.V. & Smith, C.L. 1986. Purchasing principles and applications. Englewood Cliffs, New Jersey: Prentice Hall.

Jurca , V.1999. Maintenance management using the quality approach. Czech Republic: Czech University of Agriculture.

Keller P, A. 2003. Quality Engineering Handbook. 2nd ed: United States of America: Prentice Hall

Kumar, D, & Mandloi , R.K. 2013. Analysis and Prospects of Modification in Belt Conveyors: International Journal of Engineering Research and Applications, 3(1): pp.581-587

Smith, D.J. & Babb, A.H. 1973. Maintainability engineering. New York: John Wiley & Sons.

Smith, G.F. 2000. Too many types of quality problems. New York: John Wiley & Sons

Stamatis, D.H. 2003. Six sigma for financial professionals. New Jersey: John Wiley and Sons.

Niebel, B.W. 1994. Engineering maintenance management. New York: Marcel Dekker.

Hatala, J. & Maras, M.1997. Application of the method finite elements by numerical modelling stress-strain state in conveyor belts. Acta Montanistica Slovaca 2, pp. 101-108.

Moncska, R. , Trent, R. and Handfield , R. 2005. Purchasing and supply chain management. 3rd ed. United States of America: Thomson Corporation.

Magad, E.L. & Amos, J.M. 1995. Total materials management: Achieving maximum profits through materials logistics operations. 2nd ed. United States of America: Chapman & Hall.

Montgomery, D.C., Jennings, C.L., Pfund. 2011. Managing, controlling and improving quality. United States of America. John Waley and Sons.

Pecht, M. 1995. Product Reliability, Maintainability, Supportability Handbook. Boca Raton, Florida: CRC Press.

Phadke, M.S. (1989). Quality engineering using robust design. New Jersey: Prentice-Hall

Rusiński, E., Csmochowski, J. & Mocsko, P. 2007. Failure reasons investigations of dumping conveyor breakdown: Achievements in Materials and Manufacturing Engineering, 23(1):75-78

Shah, N.M. 1988. An integrated concept of materials management. New Delphi: Tata McGraw-Hill Publishing.

Taylor, G.M. 2009. Lean six sigma service excellence. United States of America: Ross Publishing.

Tjabadi, S. Steyn , H.J. and Flaherty, P. 2012. Eskom supplier contractor quality specification – QM58.

Oahland, J. 2003. Total quality management. 3rd ed. Great Britain: Oxford Publishing.

Wolkins, D. 1995. Total Quality: A Framework for Leadership. Management Leadership Series. New York: Productivity Press.

Annexures

Appendix 1: Invitation letter to participate in survey question are

MASTER IN ENGINEERING DEVELOPMENT AND MANAGEMENT (NWU)

TEMPLATE DOCUMENTS

PARTICIPANT INFORMATION SHEET

07 August 2015

Title: QMS to improve conveyor system performance: Lethabo case study

Dear Prospective Participant

My name is Lalamani Budeli and I am doing research with Prof Johan Fick towards a Master in engineering, development and management Degree, at the North West University. We are inviting you to participate in a study entitled "Quality management system to improve conveyor system performance".

The aim of the study is to determine the influence/impact that application of quality management principles and practices in implementing QMSs will have on efficiency and effectiveness of organisations. I am conducting this research to achieve the following objectives:

- To QMSs key success factors and conditions through theory or review of literature.
- To assess quality management implementation within Eskom against key success factors and conditions.
- To identify performance gaps and misalignment between practiced and accepted quality management best practices and principles, practices and experiences.
- To establish quality improvement areas and therefore determining project for improvement

The survey is structured using Likert scale of one to five therefore not take too much of an effort and time to complete. It is estimated that it shouldn't take more than 10 to 20 minutes to get the entire questionnaire completed. If you require any further assistance, please send me an email at lalamanibudeli@gmail.com

Thank you for taking time to read this information sheet and for participating in this study.



Lalamani Budeli

M-Eng Research Student at North West University

Technical Support Manager: Eskom Lethabo Power Station

Appendix 2: Process data for conveyor system

Date	Performance	% Average	Average Tons/hour	Daily capacity (Actual)	Daily capacity (planned)	Day (24 hour)	Daily actual (H)
02/07/2015	0.00%						
03/07/2015	88.57%	44.29%	912.271	21894.504	49440	24	10.6284
04/07/2015	96.86%		0	0	49440	24	0
05/07/2015	91.14%		0	0	49440	24	0
06/07/2015	96.57%	94.86%	1954.0473	46897.136	49440	24	22.7656
07/07/2015	81.14%		0	0	49440	24	0
08/07/2015	93.71%		0	0	49440	24	0
09/07/2015	98.86%	91.24%	1879.4753	45107.408	49440	24	21.8968
10/07/2015	96%		0	0	49440	24	0
11/07/2015	98.86%		0	0	49440	24	0
12/07/2015	92.00%	96%	1969.772	47274.528	49440	24	22.9488
13/07/2015	68.00%		0	0	49440	24	0
14/07/2015	46.86%		0	0	49440	24	0
15/07/2015	17.43%	44.10%	908.39133	21801.392	49440	24	10.5832
16/07/2015	87.14%		0	0	49440	24	0
17/07/2015	99.14%		0	0	49440	24	0
18/07/2015	97.43%	94.57%	1948.142	46755.408	49440	24	22.6968
19/07/2015	92.57%		0	0	49440	24	0
20/07/2015	97.71%		0	0	49440	24	0
21/07/2015	100.00%	96.76%	1993.256	47838.144	49440	24	23.2224
22/07/2015	56.29%		0	0	49440	24	0
23/07/2015	84.29%		0	0	49440	24	0
24/07/2015	59.14%	66.57%	1371.4107	32913.856	49440	24	15.9776
25/07/2015	98.57%		0	0	49440	24	0
26/07/2015	100.00%		0	0	49440	24	0
27/07/2015	86.29%	94.95%	1956.0387	46944.928	49440	24	22.7888

Appendix 3: Material Pareto analysis table (80:20 principle)

Material	Min	Max	Available	BUn	Bin	Material Description	Mov Avg Price
0025445	2	2	2	EA	HPAC02	COUPLING,SHFT HLF:RIGID DRIVE;45 MM;STL	18310.60
0030090	3	6	6	EA	GIEG01	BRG,RLR:22232CCKC3;SELF ALIGNING	4382.09
0031153	3	4	4	EA	HCCF01	BRG,RLR:23144CCKW33C3;23144CCKW33	11000.00
0031157	5	8	1	EA	GHKA01	BRG,RLR:23136CCKW33;SELF ALIGNING	5614.22
0031488	4	6	12	EA	GHRE01	BRG,RLR:01B-150EX;SPLIT;ID 150 MM	15357.30
0031771	2	2	2	EA	HCAC06	HOUSING,BRG UNIT:150GR;PILLOW BLOCK;CI	6636.30
0031771	2	2	4	EA	HCAC06	HOUSING,BRG UNIT:150GR;PILLOW BLOCK;CI	6636.30
0034715	2	3	3	EA	HCCC01	BRG,PLBLK:SD3136TS;ID 195 MM;4;CI	4670.72
0034715	2	3	8	EA	HCCC01	BRG,PLBLK:SD3136TS;ID 195 MM;4;CI	4670.72
0034770	1	2	2	EA	HCBE01	BRG,PLBLK:SD3144TS;ID 200 MM;4;BOLT M36	6800.00
0036808	7	18	10	EA	GMTC02	PLUG,FUSE:CORE STL;18 MM;140 DEG C	207.00
0037174	2	4	2	EA	GMCE01	NOSSLE:4-STD-009;SPRAY	5393.00
0041402	1	2	2	EA	HPBE01	COUPLING,SHAFT:WINFLEX;180 MM;OD 415 MM	93327.00
0068883	1	1	1	EA	GXLG01	ASSY:PRESS RELIEF VLV & PBODY	16400.00
0100140	5	8	10	EA	RJCA01	SEAL,LBRNTH:OTL160MM;BEARING;AL	3815.68
0100140	5	8	32	EA	RJCA01	SEAL,LBRNTH:OTL160MM;BEARING;AL	3815.68
0159815	1001	2500	1500	L	KIAA01	CLEANER:DEGREASER;LIQUID;25 L	35.50
0161224	681	2100	1680	L	OEDA01	OIL,INDUS:CASTROL ALPHA SP 220;GEAR	25.32
0161230	601	1200	850	KG	OBAA02	GREASE,INDUST:MP;-30 TO 120 DEG C;BROWN	37.88
0161230	601	1200	10	KG	OBAA02	GREASE,INDUST:MP;-30 TO 120 DEG C;BROWN	37.88
0161249	2000	3150	4410	L	OBAA01	OIL,INDUS:BP ENERGOL HLP32;DRUM 210 L	22.12
0182420	101	210	150	EA	FNA06	IDLER,GRLND:V RETURN;FACE WD 770 MM	842.82
0182420	101	210	110	EA	FNA06	IDLER,GRLND:V RETURN;FACE WD 770 MM	842.82
0182421	121	200	260	EA	FNA05	IDLER,GRLND:TROUGHING;FACE WD 550 MM;STL	1471.21
0186899	2	2	1	EA	HMDB03*2*	CLUTCH:AL150-F54-D24;HOLDBACK;150 MM	18000.00
0213786	1	1	14	EA	H0BF03	BELLOWS,PRESS:BLOWER ;0-100 KPA ;PTFE	9232.15
0213786	1	1	1	EA	H0BF03	BELLOWS,PRESS:BLOWER ;0-100 KPA ;PTFE	9232.15
0591047	201	500	463	EA	TCCCA01	FLASHLIGHT:(4) AAA;CLEAR;PLASTIC;7.2 WH	505.70

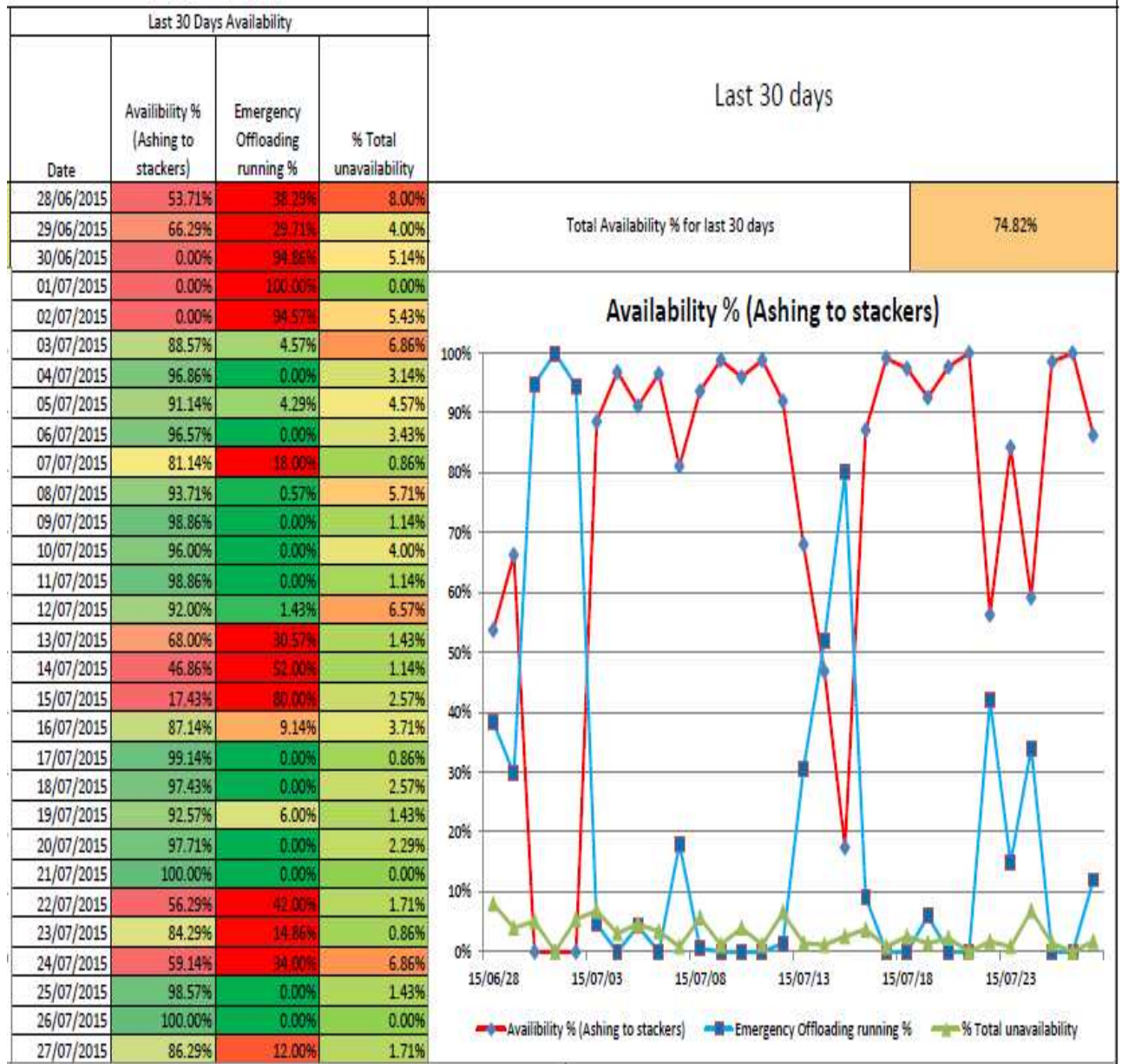
Appendix 4: Root cause analysis using FMEA on processes

Material Document	Material	Process affected by failure mode (FMEA)	Material Description	Qty in Unit. of entry	Unit of Entry
4906520353	31488	Engineering	BRG,RLR:01B-150EX;SPLIT;ID 150 MM	-2	EA
4906520352	31770	Maintenance	BRG,RLR:01B-150MMGR;SPLIT;ID 150 MM	-2	EA
4906534800	182420	Engineering	IDLER,GRLND:V RETURN;FACE WD 770 MM	-200	EA
4906534800	182421	Engineering	IDLER,GRLND:TROUGHING;FACE WD 550 MM;STL	-120	EA
4906568689	25445	Engineering	COUPLING,SHFT HLF:RIGID DRIVE;45 MM;STL	-2	EA
4906581130	185331	Maintenance	ASSY:2/8.54;CARRIER;ASH CONVEYOR	-4	EA
4906666311	185331	Maintenance	ASSY:2/8.54;CARRIER;ASH CONVEYOR	-4	EA
4906694143	182421	Engineering	IDLER,GRLND:TROUGHING;FACE WD 550 MM;STL	-30	EA
4906732407	27503	Maintenance	PINION:SPUR;ID 49 X OD 136 X WD 40 MM	-4	EA
4906739181	27503	Engineering	PINION:SPUR;ID 49 X OD 136 X WD 40 MM	-2	EA
4906741660	27503	Engineering	PINION:SPUR;ID 49 X OD 136 X WD 40 MM	-10	EA
4906740274	591047	Maintenance	FLASHLIGHT:(4) AAA;CLEAR;PLASTIC;7.2 WH	-23	EA
4906759523	161230	Engineering	GREASE,INDUST:MP;-30 TO 120 DEG C;BROWN	-150	KG
4906832203	159815	Material	CLEANER:DEGREASER;LIQUID;25 L	-250	L
4906832004	161230	Engineering	GREASE,INDUST:MP;-30 TO 120 DEG C;BROWN	-150	KG
4906883566	161249	Maintenance	OIL,INDUS:BP ENERGOL HLP32;DRUM 210 L	-420	L
4906884454	161224	Maintenance	OIL,INDUS:CASTROL ALPHA SP 220;GEAR	-420	L
4906916594	36808	Procurement	PLUG,FUSE:CORE STL;18 MM;140 DEG C	-18	EA
4906920409	27503	Procurement	PINION:SPUR;ID 49 X OD 136 X WD 40 MM	-2	EA
4906920090	31153	Procurement	BRG,RLR:23144CCKW33C3;23144CCKW33	-2	EA
4906920503	31157	Engineering	BRG,RLR:23136CCKW33;SELF ALIGNING	-2	EA
4906920103	34715	Maintenance	BRG,PLBLK:SD3136TS;ID 195 MM;4;CI	-2	EA
4906921607	44458	Engineering	PUMP,ROTARY:GEAR;32 MM	-2	EA
4906922977	100140	Engineering	SEAL,LBRNTH:OTL160MM;BEARING;AL	-14	EA
4906921605	182421	Material	IDLER,GRLND:TROUGHING;FACE WD 550 MM;STL	-85	EA
4906923959	30090	Material	BRG,RLR:22232CCKC3;SELF ALIGNING	-2	EA
4906928583	68883	Material	ASSY:PRESS RELIEF VLV & PBODY	-1	EA
4906929501	31488	Engineering	BRG,RLR:01B-150EX;SPLIT;ID 150 MM	-2	EA
4906932176	25445	Engineering	COUPLING,SHFT HLF:RIGID DRIVE;45 MM;STL	-2	EA
4906932243	31771	Maintenance	HOUSING,BRG UNIT:150GR;PILLOW BLOCK;CI	-4	EA
4906932177	34770	Maintenance	BRG,PLBLK:SD3144TS;ID 200 MM;4;BOLT M36	-2	EA
4906932302	41402	Engineering	COUPLING,SHAFT:WINFLEX;180 MM;OD 415 MM	-1	EA
4906932241	177246	Maintenance	STOP:100NRT;TORQUE ARM;STL	-1	EA
4906932179	186899	Material	CLUTCH:AL150-F54-D24;HOLDBACK;150 MM	-1	EA
4906932301	213786	Engineering	BELLOWS,PRESS:BLOWER ;0-100 KPA ;PTFE	-4	EA
4906934647	97540	Maintenance	PACKING,BULK:222G;WD 7.9 MM;THK 7.9 MM	-8	KG
4906937251	37174	Engineering	NOSSLE:4-STD-009;SPRAY	-2	EA
4906977612	31157	Engineering	BRG,RLR:23136CCKW33;SELF ALIGNING	-2	EA
4906979002	161249	Maintenance	OIL,INDUS:BP ENERGOL HLP32;DRUM 210 L	-420	L

Appendix 5: Actual and budgeted cost for 2014/15 financial year

1SLK		CContrs: Current Period / Cumulative			
Date:	24.06.2015				
Pages:	5				
Requested by:	Z4554875				
Controlling Area	1000				
Period	12				
Fiscal Year	2014/2015				
Plan Version	0				
Cost Element Group	E_PS_COST				
Cost Center Group	320258,320				
	Material	External services	General expences	Monthly Actual	Monthly Budget
Period 1	617593.04	19795.9	10476.73	647864	1118073
Period 2	504491.86	370556.89	4178.47	879225	1128575
Period 3	1608558.88	185748.1	31450	1825756	1120905
Period 4	900894.52	585946.05	-31450	1518296	1192295
Period 5	1116154.77	291332.25	12956.05	1420442	1200555
Period 6	-352958.56	354981.06		1429543	2007848
Period 7	1272775.93	101912.75	16485	1391172	1195835
Period 8	2160649.34	891644.93		3052293	1123265
Period 9	544058.74	545902.15	23136	1113096	1117955
Period 10	1024436.89	139341.45		1163777	1123855
Period 11	1085478.67	490436.74	-1500	1577414	1126805
Period 12	3767305.95	522679.2	1657.5	4291641	1117837
Total	14249440.03	4500277.47	67389.75	20310519	14573803

Appendix 6: Ash plant process experimental data



Appendix 7 : 2014/15 financial year monthly and overall performance

Subgroup	Costs		operating hours		Capacity		Line speed (m/s)
	Budgeted (R)	Actual (R)	Actual Run (hour)	Total Monthly (hours)	Actual Ash (ton)	Total Monthly Ash Capacity (tons)	
1. March	1118073	647864	440	720	519810.28	602361	2.87
2. April	1128575	879225	580	720	530777.5813	602361	2.87
3. May	1120905	1825756	591	720	554621.3536	602361	2.87
4. June	1192295	1518296	558	720	535731.3893	602361	2.87
5. July	1200555	1420442	578	720	445060	602361	2.87
6. August	2007848	1429543	487	720	374990	602361	2.87
7. September	1195835	1391172	305	720	234850	602361	2.5
8. October	1123265	3052293	280	720	215600	602361	2.5
9. November	1117955	1113096	203	720	156310	602361	2.5
10. December	1123855	1163777	227	720	174790	602361	1
11. January	1126805	1577414	497	720	382690	602361	1
12. February	1117837	4291641	578	720	445060	602361	2.87
Totals	14573803	20310519	5324	8640	4570290.603	7228332	2.87
Annual output	1.393632053		0.6162037		0.632274583		
	39 % overspend		62 % operating hours		annual performance of 63%		

Appendix 8: Survey questionnaire (Reff:

<http://unpan1.un.org/intradoc/groups/public/documents/apcity/unpan012140.pdf>)

Importance (The level of perceived importance of the factor)	1 = Not important at all , 2 = Not important, 3 = Neutral important, 4 = Important, 5 = Very important		
PRACTICE (The extent or degree of practice in ash plant)	1 = Very low , 2 = Low ,3 = Moderate, 4 = High, 5 = Very high		
		Scale:(1-5)	Scale: (1-5)
	Factors	Importance	Practiced
F1: Management Leadership	1. Top management ensures that every employee knows the company's mission and business objectives.		
	2. Top management strongly promotes staff involvement in quality management and improvement activities		
	3. Managers and supervisors empower employees		
	4. Communication links are established between employees and top management		
	5. Top management takes care of employee well being		
	6. Company fulfils its social responsibilities		
F2: Resource Management	1. Human resource ability considered in improvement activities		
	2. Employees are given information and training they need to do the job effectively.		
	3. Employees are given tools they need to do the job effectively.		
	4. Sufficient financial resources provided to support improvement activities.		
	6. Company manages its material resources effectively.		
F3: Measurement and Feedback	1. Customer satisfaction level are measured and monitored.		
	2. Information on quality and customers are collected and analysed.		
	3. Information on operational and financial performances are collected and analysed.		
	4. Employees' views are listened to and acted upon.		
	5. Employee performance are measured and recognised.		

F4: Continuous Improvement	1. There is a quality improvement coordinating body		
	2. Improvement teams are active in all departments.		
	3. Quality improvement tools and techniques are widely used.		
	4. The company practices continuous improvement of all its products, services, and processes		
F5: Supplier Quality Management	1. Suppliers are selected on the basis of quality aspects.		
	2. Company ensures that suppliers can maintain high technical standards and meeting quality specifications.		
	3. Company regularly conducts suppliers' quality audits.		
	4. Company works closely with suppliers toward long term partnership and improvement.		
	5. Suppliers provide relevant quality records and data.		
F6: Systems and Processes	1. Systems and procedures for quality assurances are implemented.		
	2. Internal data collection system is established.		
	3. Market information and feedback system is established.		
	4. The employees involved in different processes know how to evaluate them.		
F7: Education and Training	1. Top management always updates their knowledge.		
	2. Employees are trained for job related skills.		
	3. Employees are trained on total quality concepts.		
	4. Continuous learning is provided through education and training		
F8: Work Environment and Culture	1. A pleasant environment exists in all working areas.		
	2. Positive values such as trust, honesty, hardworking, are fostered by management.		
	3. Teamwork and involvement are normal practices in the company.		

	5. The company adopts 'Employee satisfaction' initiatives		
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Appendix 9 : Barriers to TQM implementation questionnaire

Barriers to TQM implementation	Degree of agreement (1-5)
1. Lack of understanding.	
2. Lack of preparation (No budget, no sponsor).	
3. Resistance to change (Too busy)	
4. Lack of vision.	
5. Lack of top management commitment.	
6. Lack of customer focus.	
8. Lack of resources.	
9. Lack of systems and structures for TQM activities.	
10. Availability to training.	
11. Training with no purpose.	
12. Costly consultancies, training programs.	
13. Lack of rewards and recognition.	
14. Lack of effective measurement criteria.	
15. Lack of evaluation procedures and benchmark indices	

Appendix 10 : Quality work elements

<p>CONDITION MONITORING/RELIABILITY ENGINEERING</p>	<p>Establishing reliability goals Reliability apportionment Stress analysis Identification of critical parts Failure mode, effects, and criticality analysis (FMECA) Reliability prediction Design review Supplier selection Control of reliability during manufacturing Reliability testing Failure reporting and corrective action system</p>
<p>QUALITY ENGINEERING</p>	<p>Process capability analysis Quality planning Establishing quality standards Test equipment and gage design Quality troubleshooting Analysis of rejected or returned material Special studies (measurement error, etc.)</p>
<p>QUALITY ASSURANCE</p>	<p>Write quality procedures Maintain quality manual Perform quality audits Quality information systems Quality certification Training Quality cost systems</p>
<p>INSPECTION AND TEST</p>	<p>In-process inspection and test Final product inspection and test Receiving inspection Maintenance of inspection records Gage calibration</p>
<p>VENDOR QUALITY</p>	<p>Pre-award vendor surveys Vendor quality information systems Vendor surveillance Source inspection</p>

Appendix 11: Chi-square distribution table

<i>df</i>	$\chi^2_{.995}$	$\chi^2_{.990}$	$\chi^2_{.975}$	$\chi^2_{.950}$	$\chi^2_{.900}$	$\chi^2_{.100}$	$\chi^2_{.050}$	$\chi^2_{.025}$	$\chi^2_{.010}$
1	0.000	0.000	0.001	0.004	0.016	2.706	3.841	5.024	6.635
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277
5	0.412	0.554	0.831	1.145	1.610	9.236	11.070	12.833	15.086
6	0.676	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812
7	0.989	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475
8	1.344	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090
9	1.735	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666
10	2.156	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209
11	2.603	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725
12	3.074	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217
13	3.565	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688
14	4.075	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141
15	4.601	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578
16	5.142	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000
17	5.697	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409
18	6.265	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805
19	6.844	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191
20	7.434	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566
21	8.034	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932
22	8.643	9.542	10.982	12.338	14.041	30.813	33.924	36.781	40.289
23	9.260	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638
24	9.886	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980
25	10.520	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314
26	11.160	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642
27	11.808	12.879	14.573	16.151	18.114	36.741	40.113	43.195	46.963
28	12.461	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278
29	13.121	14.256	16.047	17.708	19.768	39.087	42.557	45.722	49.588
30	13.787	14.953	16.791	18.493	20.599	40.256	43.773	46.979	50.892
40	20.707	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691
50	27.991	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154
60	35.534	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379
70	43.275	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425
80	51.172	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329
90	59.196	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116
100	67.328	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807