RELIABILITY ENGINEERING MANAGEMENT IN THE PETROCHEMICAL ENVIRONMENT: THE AIR SEPARATION UNIT

By

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2014 255 48

A mini-dissertation submitted to the faculty of Engineering and the Built Environment in partial fulfillment of the requirements for the degree

M_{PHIL} ENGINEERING MANAGEMENT

At the

UNIVERSITY OF JOHANNESBURG

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NOVEMBER 2015

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DECLARATION

I certify that the dissertation submitted by me for the degree *Master's in Engineering Management* at the University of Johannesburg is my independent work and has not been submitted by me for a degree at another university.

Richter Stadler

ACKNOWLEGEMENTS

I wish to express my thanks to my supervisor, Dr. Arnesh Telukdarie for his guidance, unfailing patience, encouragement, and invaluable contribution throughout the duration of this study.

Special thanks to my wife Elbé, who listened to my ideas and offered inspiration when it was much needed. Thank you for your loyal support.

Finally, I wish to thank our almighty God, for the grace, health, courage, and determination to complete this research study.

ABSTRACT

The key processing unit, the "cold box", is fundamentally responsible for air extraction and separation. The cold box is critical in the Sasol Chemical Industries (SCI) environment, due to the importance of oxygen in several processes. Due to the criticality of the equipment, it became necessary to streamline the maintenance process utilized on the cold box.

Irregular and unplanned maintenance can lead to unforeseen events and may have safety and environmental implications. The maintenance philosophy that is followed to maintain the equipment is of utmost importance. Sasol conducts maintenance on their cold box with a black box approach, which makes it difficult for the maintenance team to predict failures, resulting in significant losses. The study investigates the potential benefits of an alternative maintenance strategy. The key focus of the research includes an evaluation on the impact of an alternative maintenance approach has on the reliability and stability of the equipment. The research approach includes a global literature study providing potential options for improvements. The viability of these options was tested via a questionnaire conducted with plant personnel with current plant personnel. The questionnaire consists of 28 questions, which are formulated to determine certain data relating to the research question. The questions are divided into six categories, as it is extracted from the relevant sections. See details in Appendix A

The categories are:

1. Challenges in the different air separation processes
2. Maintenance management
3. Maintenance planning
4. Maintenance strategy
5. Reliability management
6. Quality management and the reliability centred maintenance (RCM) process

On completion of the data collection, the data was thoroughly validated to verify that the information is relevant to the research topic. Each maintenance management division's data was tabulated based on the response of the individuals and analyzed thoroughly to extract the conclusions of the collected data (Maxwell, 2002).

The results of the respondents indicated that proactive maintenance and all aspects thereof is the key to success for improving the reliability of the cold box. Reliability engineering management is essential for the stability of the cold box.

LIST OF ABBREVIATIONS

SCI – Sasol Chemical Industries

GOX – Gaseous Oxygen

ASU – Air Separation Unit

CTL – Coal to Liquid

NDE – Non-Destructive Evaluation

LP – Low Pressure

HP – High pressure

MTBF – Mean Time Between Functional Failures

GO – General Overhaul

CMMS – Computerized Maintenance Management System

TQM – Total Quality Management

RCM – Reliability Centered Maintenance

FMECA – Failure Mode Effect and Criticality Analysis

TPM – Total Productive Maintenance

OTF – Operate to Failure

DOM - Design Out Maintenance

RBM – Risk Based Maintenance

Sasol – South Africa Synthetic Oil Liquid

RBI – Risk Based Inspection

PCMS – Plant Condition Management System

RCFA – Root Cause Failure Analysis

WBS – Work Breakdown Structure

PSA – Pressure Swing Adsorption

SCI – Sasol Chemical Industries

SAP – Systems, Applications, Products

PCMS – Plant Condition Management Software

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

The maintenance of engineering equipment in the petrochemical industry is a complex and challenging field. Under normal and adverse conditions, maintenance has to be performed as part of a daily routine. Irregular and unplanned maintenance can lead to unforeseen events and may have safety and environmental implications. The utility division of South Africa Synthetic Oil Liquid (Sasol) Chemical Industries (SCI) consists of three critical components in the petrochemical value chain: oxygen, water works and steam. This mini dissertation will primarily focus on the Sasol cold box in the oxygen environment

Pure Gaseous Oxygen (GOX) is the core product produced in the Sasol Oxygen plant and is utilized in various processes. The key processing unit, the “cold box'', is fundamentally responsible for air extraction and separation. The air separation of several gasses is made possible by the drastic change in temperatures inside the vessel. The cold box is critical in the SCI environment due to the importance of oxygen in several processes, thus the maintenance philosophy that is followed to maintain the associated equipment is of utmost importance.

Oxygen is used in oxidation of raw chemicals for recovery of propylene oxide, nitric acid, ethylene oxide, vinyl chloride, and other chemical compounds. In the oil and gas division of Sasol petrochemical industry, oxygen is used for viscosity improvement of oil and gas flow properties. Oxygen is furthermore used for enhancing production capacity of oil cracking plants, efficiency of high-octane components processing, as well as the reduction of sulfuric deposits in refineries.

All maintenance operations of the cold box need to comply with the organization’s standards, in order to govern all maintenance activities throughout the entire organization. According to Goetsch & Davis (2010), quality management is an important approach for organizations. It can be defined as an approach to attempt to maximize an organization’s competitiveness through the quality of its processes, environments, services, people, and products. Applying quality management on all maintenance activities will raise the standard and effectiveness of maintenance for the equipment and the organization.

1.2. PROBLEM STATEMENT

The equipment under investigation is the Air Separation Unit (ASU) also known as a cold box in the SCI environment. The cold box is critical to the Coal to Liquid (CTL) process in the petrochemical industry. The need for effective maintenance is critical to ensure that equipment is stable and reliable throughout its lifespan. The cold box has limited access for online inspections and there is no opportunity for maintenance before any breakdown occurs. Online inspection is inspections that is conducted while the cold box is in operation and delivering product without being decommissioned. Online inspection is part of the inspections on the cold box that can be conducted any time and it can not lead to any production losses at all. Online inspection can be conducted if technical personnel identify the inspection method on the cold box and discuss it with the production department. If the production plan allows for inspections, they will be planned and executed as agreed by the relevant role players. The major challenge with maintaining the cold box according to specified organizational standards is that the equipment cannot be decommissioned for maintenance for more than seven consecutive days. The repair process on a complex system like the cold box can be time-consuming and can take up to six months depending on the severity of the repairs. It is crucial to repair the cold box in the least amount of time possible and the best way to determine the timeframe is to speak to the maintenance experts.

The maintenance philosophy that is followed to maintain the equipment is of utmost importance. Sasol is currently conducting maintenance on the cold box with a black box (closed box) approach which makes it difficult for the maintenance team to predict failures, resulting in significant losses. The black box approach can be described as a method of conducting maintenance with a reactive approach where failures already occurred. The reason for conducting maintenance with a black box approach is due to the extensive timeframe of the repair process that is followed on the equipment. The production losses during a cold box overhaul process are of such a nature that it negatively affects the production schedule throughout the entire company. Maintenance on equipment should comply with a safe working environment and must be cost effective for competitiveness (Mishra & Pathak, 2012).

Investing time and resources in developing effective maintenance strategies ensures stable and predictable operations. The effectiveness of the derived maintenance strategies determines how well a department or function meets its goals. This will allow the organization to minimize the indirect costs of maintenance associated with production losses (Crespo Ma´rquez et al., 2009). If the maintenance strategies are followed correctly, the interval between breakdowns on the equipment will indicate when the equipment has reached its redundancy phase.

There has been a strategic change in terms of maintaining the cold box in Sasol and this research will focus on the maintenance strategy to be followed to improve the current black box maintenance approach. The high demand for oxygen in SCI processes made it beneficial for Sasol to investigate into new maintenance strategies. It is now evident that an alternative method needs to be tested to both ensure stable and reliable operations for Sasol and for it to be as efficient and effective as possible.

1.3. RESEARCH QUESTION

Maintenance on the cold box cannot always be conducted as required to enhance productivity in the petrochemical industry. The cold box is a critical component to the Sasol Coal to Liquid (CTL) petrochemical process. The maintenance department must ensure that the cold box is availible to meet Sasol's oxygen demand. The argument is that Sasol is currently doing maintenance on the cold box with a black box approach which make it difficult for the maintenance team to predict when a failure might occur. The core focus of this study is to determine if an alternative maintenance strategy can be implemented on the cold box to improve the reliability and stability of the cold box.

The research question is derived from Sasol's requirement for a streamlined oxygen output.The reseach question: What can be done to improve the reliability and stability of the cold box to enhace its oxygen output?

1.4. WHY THIS FIELD OF STUDY IS UNIQUE

The cold box was constructed in 1978, designed to operate for 30 years and thereafter be demolished. Since 1978 no repairs have been done, as the vessel is surrounded with an insulation agent called perlite. The first cold box was decommissioned in 2012 after a severe leak of liquid oxygen was detected on the outside of the frame of the cold box. Since the completion of the repair process, the need for an improved maintenance philosophy was developed. Perlite is produced from a vitreous rock from the lava of underwater volcanoes. The majority of perlite needs to be imported from southern Europe and South America, which makes it a very expensive product (Pfundstein et al., 2007). Perlite is a white powder that has a very low density and is used frequently in the building environment for the insulation of roofs. In order to do maintenance on the cold box and surrounding piping and equipment, perlite must be extracted. This is time-consuming and costly.

The cold box, with its complete interconnecting piping system, is extremely costly. This forced Sasol to do a Non-Destructive Evaluation (NDE). NDE is the examination of an object with technology that does not affect the object's future usefulness (Shull, 2002). NDE's can determine if the equipment is efficient for service and if it will be able to deliver the intended production capacity. If the equipment is efficient for service, further tests will be conducted to determine the theoretical life span of the equipment. On completion of the cold box NDE's, it was discovered that the equipment was still effective and efficient to perform the intended function as per original design in the air separation process.

The research being conducted on the cold box is unique because of the value that the equipment adds in terms of supplying oxygen to the Sasol process. The traditional maintenance approach that is performed on the cold box is a black box approach. The strategy around this equipment need to change, it has to be maintained differently to maximize the value that the equipment adds to the Sasol process. The value of this research is the proposal of an alternative maintenance strategy to maintain the cold box and additional research on maintenance management to maximize the equipment's value in the entire Sasol environment. This research will enable a new strategy to reduce the overhaul downtime, which can improve production output and assure that the cold box is more cost effective and reliable.

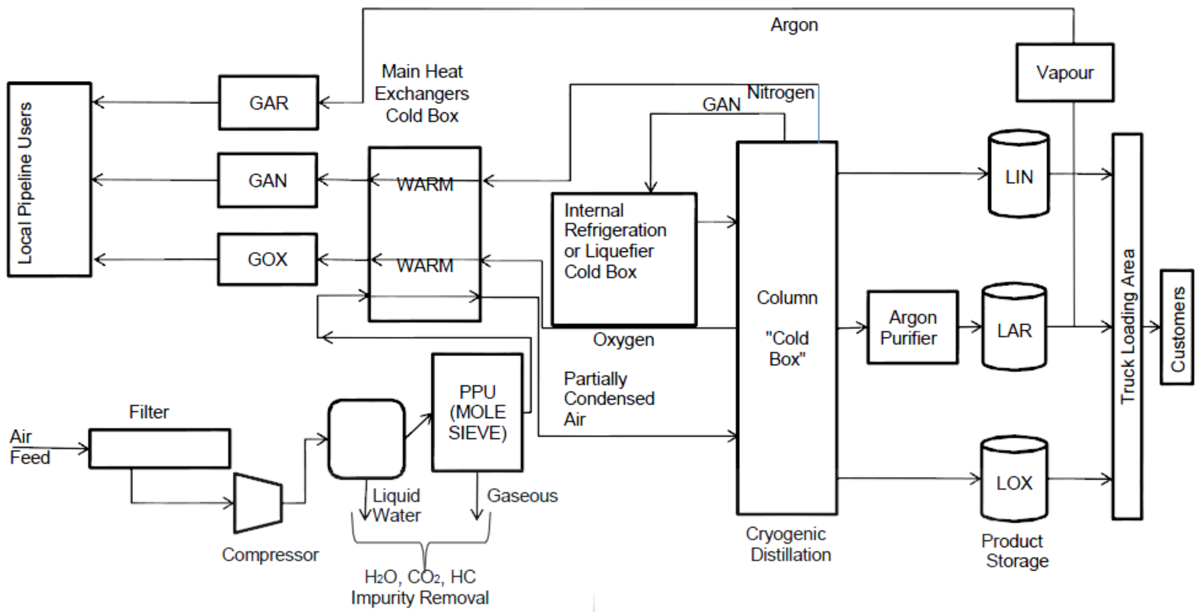
CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION TO THE COLD BOX

The ASU in the oxygen environment is commonly referred to as the cold box, which consists of sixteen main pieces of equipment and an interconnecting piping system linking the entire system. A cold box is a very tall rectangular structure that is filled with perlite which serves as isolation agent. The perlite and rock wool minimize convection currents in the enclosure. The physical size of a cold box in the oxygen plant in Sasol is 7 m in length and breadth and the box is 30 m high. In other petrochemical industries, cold boxes can differ in sizes between 2 m and 7 m in breadth and it can be from 15 m up to 60 m depending on the plant's production requirements (Universal Industrial Gasses, 2013). The first major unforeseen breakdown of a cold box occurred in January 2012 in the Sasol oxygen environment. The root cause of the breakdown was a result of the contraction and expansion of the stainless steel material due to the temperature changes on a regular basis over years. The material is suitable and chosen for the temperature changes, but the isolation should always be in place. The failures occurred where the interconnecting piping sytem enter the vessel inside the cold box on the weld seams. Severe leaks were generated without the maintenance teams' knowledge and then later resulted in huge ice formations. The ice formation later started to damage the internal piping as it came loose.

Sasol's oxygen demand is very high and therefor the process followed to extract oxygen from air is called cryogenic air separation. The research is based on the Cryogenic Air Separation method of extracting oxygen from the atmosphere and the maintenance method to apply for maximizing the cold box's production output. The research will highlight the importance of maintenance management and the reliability of equipment. See figure 1 as illustration for the cryogenic air separation process.



Gaseous	Product	Liquid
GAN	Nitrogen	LIN
GAR	Argon	LAR
GOX	Oxygen	LOX
CO_2	Corbon Dioxide	-
H_2O	Water	H_2O
HC	Hydrocarbons	-

Generic Air Seperation Unit (ASU)
Shows inter-relationship of major components
Specific plant will vary

Figure 1: The cryogenic air seperation flow diagram (Universal Industrial Gasses, 2013)

Listed below are the five basic steps in the cryogenic air separation process.

Step 1 (filtering, compressing and cooling of incoming air):

In a cryogenic air separation plant the first step will be to filter and compress air extracted from the atmosphere. The compression takes place at around 500 to 800 kPa (Universal Industrial Gasses, 2013). The compressed air is then cooled down and the water vapor in the incoming air is removed. The cooling process is achieved through means of a series of air-cooled heat exchangers. The cooling water utilized in the heat exchangers is cooled down in a chill water tower to lower the temperature to enhance and stabilize the overall air separation process. On completion of each stage of cooling and compression, condensed water is separated from air and rerouted to the cooling water system (Amarkhail, 2009).

Step 2 (removal of impurities):

The next step is to remove all remaining carbon dioxide and water vapor. Impurities should always be removed to ensure product quality specifications are met. These impurities must be completely removed prior to air entering the distillation column as it will freeze inside the process equipment (Amarkhail, 2009). The two most commonly used methods to remove impurities are molecular sieve units and reversing heat exchangers. The newer air separation plants use the molecular sieve units (Universal Industrial Gasses, 2013).

Step 3 (bring the air feed to cryogenic temperature):

The next step in the process is to cool down air feed to cryogenic temperature of approximately -185°C (Universal Industrial Gasses, 2013). This cooling process is performed in a brazed aluminum heat exchanger that allows heat exchange between the incoming air feed, the cold product, and the waste gas streams that exit during the separation process. The extreme cold temperature required for the cryogenic distillation process is created using a refrigeration process that includes one or more elevated process streams (Amarkhail, 2009).

Step 4 (distillation, where air is separated into different desired products):

In this step, distillation columns separate the incoming air into desired products. The distillation system for oxygen has high pressure column at the top and low pressure columns at the bottom in series (Amarkhail, 2009). Oxygen leaves from the bottom distillation column and nitrogen from the top distillation column. Often a nitrogen plant will only have one column, but having two is more common. Impure oxygen is produced in the high pressure column and is purified further in the lower pressure column. The purer the cryogenic gas a plant is required to produce, the more distillation stages the plant should have to make use of (Universal Industrial Gasses, 2013).

Argon and oxygen have a similar boiling point, so in order to obtain high purity oxygen, the argon needs to be removed from the distillation system. The removal of argon takes place in the low pressure column, where the highest concentration of argon will be present (Universal Industrial Gasses, 2013).

Step 4 covers the process that takes place in the cold box, which is part of the cryogenic air separation process. This step takes place in a very low temperature environment. Therefore, the distillation columns, heat exchangers, and cold piping must be well-isolated at all times. The inside of the cold box is purged with nitrogen to keep out any oxygen and moisture.

Step 5 (refrigeration is produced at cryogenic temperature levels):

The refrigeration cycle that is used in air separation plants is similar to those of home and automobile air conditioning systems. The pressure in one or more elevated pressure streams is reduced and the stream is then chilled.

Gaseous products generally leave the cold box at a relatively low pressure, often just over one atmosphere. In most plants, higher efficiency of the separation and purification processes will result in lower delivery pressure (Universal Industrial Gasses, 2013).

The cold box is only one process to extract pure oxygen from the atmosphere. There are other methods that can be followed to extract oxygen and they will be discussed 2.2.1 up to 2.2.3 along with why Sasol do not use these processes in their operations.

2.2 DIFFERENT PROCESSES OF MAKING OXYGEN

Oxygen can be extracted from the atmosphere through different processes. The process selected in a petrochemical industry depends on the quantity, purity level, and production output as well as company resource availability. Listed and discussed below are three air separation processes to extract oxygen from air.

2.2.1 Cryogenic air separation

Cryogenic air separation is a process that is commonly used in petrochemical industries across the globe and Sasol use this process due to its satisfactory production specifications. The process offers a high volume of oxygen at an extremely high purity. The process is explained in the introduction to the cold box section 2.1.

	CONVENTIONAL PROCESS			NEW PROCESS		
Product	**Flow rate**	**O_2**	**N_2**	**Flow rate**	**O_2**	**N_2**
O_2 (g)	8038	99.99	0.01	9189	99.98	0.02
N_2 (g)	10602	0.13	99.87	11178	0.13	99.87
Waste N_2 (g)	31360	7.65	92.35	29633	4.21	95.79
The flow rate in Nm^3 /h and composition in mole %						

Table 1: Product streams in a cryogenic air separation process (Khalel et al., 2013)

As noted in Table 1 the purity of oxygen is 99.98%, which is almost pure oxygen and the purity is monitored to prevent it from losing purity. At a large oxygen plant in a petrochemical industry the output of oxygen for an air separation unit can vary from 50 000 Nm^3/h to 100 000 Nm^3/h depending on the demand of the entire factory. The majority of air separation in various industries is done via cryogenic distillation as the process is highly energy efficient in large scale plants **(Drioli & Barbieri, 2011)**.

2.2.2. Membrane air separation

In a membrane air separation system, compressed air is fed into one side of the membrane. Gasses and liquids with higher infiltration abilities than nitrogen infiltrate through the membrane leaving mostly nitrogen behind. The product gas quality required by the end user determines the membrane selection and operation conditions for the process **(Drioli & Barbieri, 2011)**. Figure 3 explains the membrane air separation process schematics. The figure has two sections, A indicates oxygen enriched air and B indicates pure oxygen.

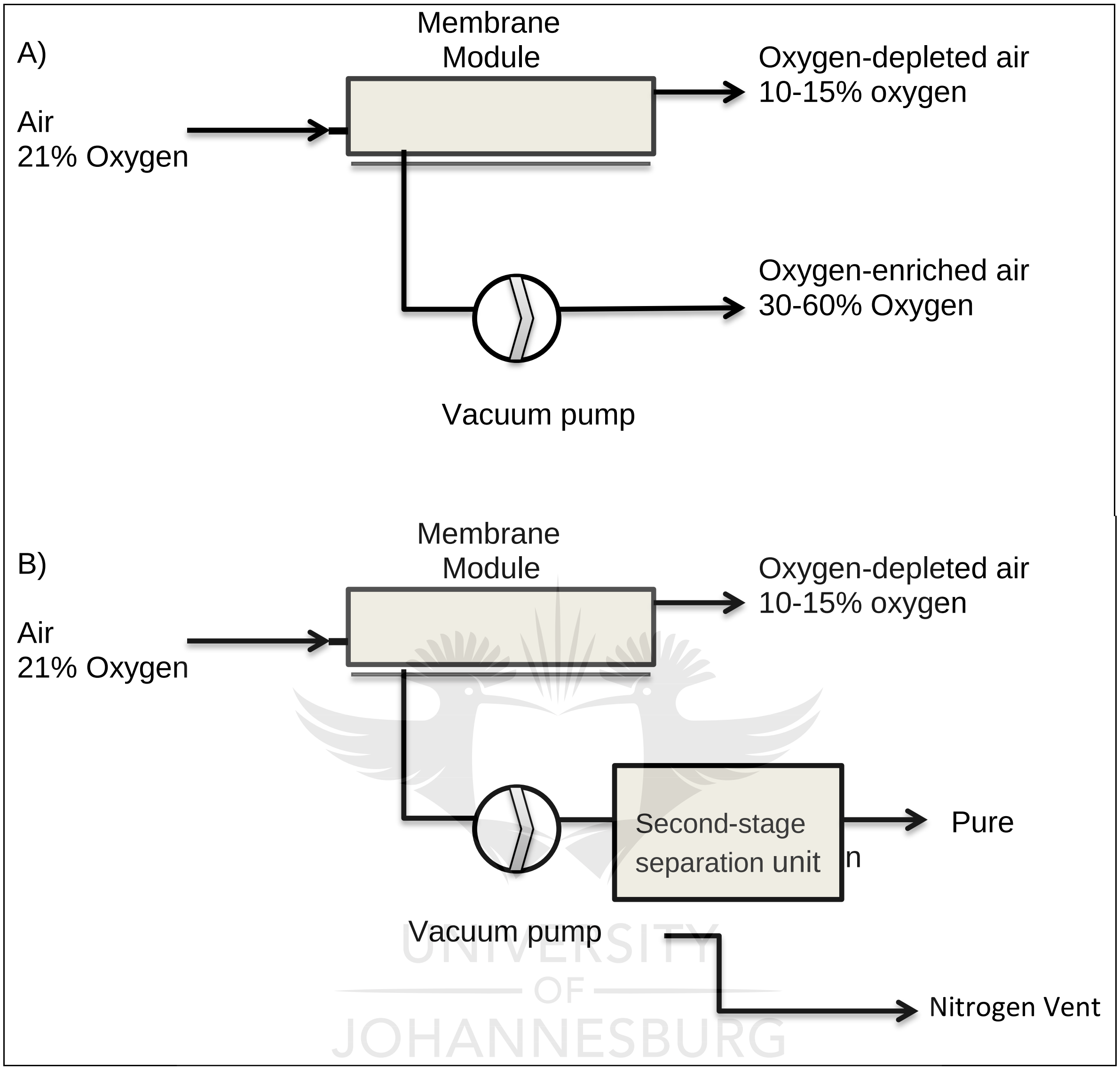


Figure 2 : Membrane process flow schematics **(Ismail et al., 2015)**

Polymeric air separation membranes are the preferred commercial membrane air separation applications. The process is used to generate very low purity nitrogen gas in small quantities in locations where it is difficult to access. Industrial oxygen requires 90% purity or more which cannot be achieved through polymeric membrane systems and therefore not many polymeric membrane systems are used for the production of oxygen in petrochemical companies such as Sasol as the purity needs to be as close as possible to 100% (Drioli & Barbieri, 2011). Oxygen can be extracted with ion transport membranes which are manufactured from various and mixed metal oxide materials. These are developed for oxygen produced from air at a slightly elevated temperature (Drioli & Barbieri, 2011).

2.2.3. Separation by adsorption

Pressure swing adsorption (PSA) is one of the most commonly used adsorption processes in the air separation industry. This PSA process is disclosed in a patent by Skarstrom in 1958. The PSA process is not a commercially used process for oxygen extraction, but is used more for air drying. The oxygen recovery is too low and the energy requirement too high to be economical (Yang, 2013). The Skarstrom cycle is better illustrated in the figure below.

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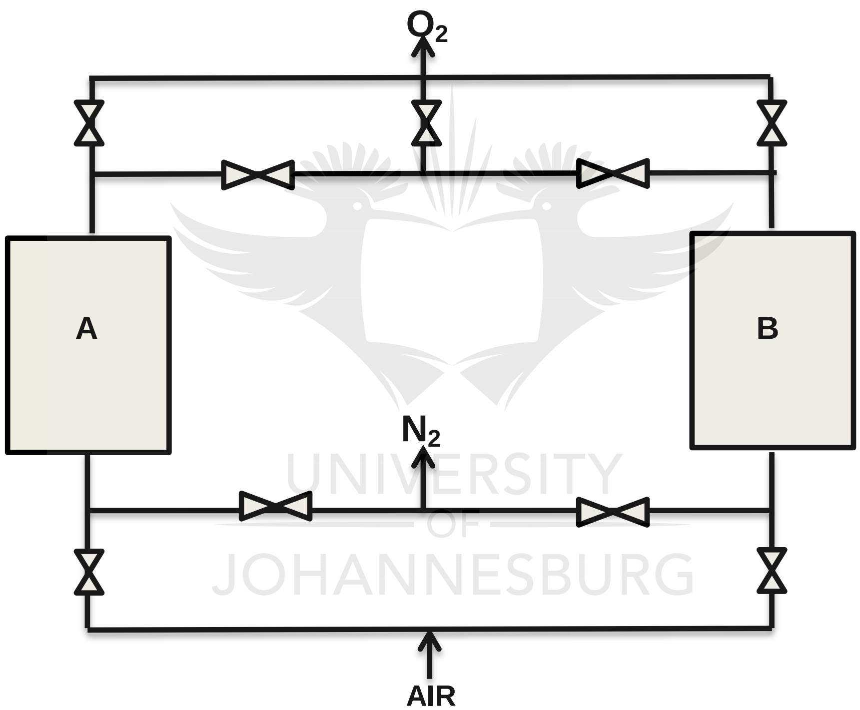


Figure 3: The Skarstrom cycle (Yang, 2013)

The Skarstrom cycle consists of two main steps for each bed. The first is re-pressurization which is followed by feed in A, while oxygen is withdrawn. The second step is the purge and blow down with oxygen of A while nitrogen is withdrawn. In B the function of A is reversed in the follow up cycle (Yang, 2013).

2.3. CHALLENGES IN THE DIFFERENT AIR SEPARATION PROCESSES

In all industries, the set-out production specifications are different, and the chosen air separation process should comply with the company's demand to be successful in the industry. The oxygen purity level required through the Sasol operations can be a minimum of 98.6% pure and maximum of 100% pure. The oxygen purity is measured on the Low Pressure (LP) column and is manipulated with the reflux (lean liquid from the high pressure (HP) column) to a purity of 98.6% as per agreement with the factory requirement. The distillation column itself can produce up to 100% purity but Sasol operate it at 98.6% optimum, considering saving energy as well. The quantity of oxygen required is extremely high for normal operations. The Sasol Secunda factory utilizes an average of 1 000 000 Nm^3/h oxygen. As an indication of the large quantity of oxygen utilized by the factory, it can be converted to a mass of 1 428 200 kg/h of oxygen. Sasol has sixteen oxygen units where fourteen of the units deliver 72 000Nm^3/h at a purity of 98.6% and the other two units deliver 103 000 Nm^3/h at a purity of 98.6%. The oxygen flow is measured on each oxygen compressor and on the oxygen header pipeline. There are some major challenges in each air separation process which can cause companies to under-deliver in the market. Listed below are the three different processes and some of the challenges that might occur in industries.

2.3.1. Cryogenic air separation can create major safety problems when hydrocarbons are present in the inlet air feed. These hydrocarbons must be removed prior entering the distillation column. It is very difficult to remove all hydrocarbons from the process. The hydrocarbons usually are removed through refrigeration purification and/or solid absorbent purification (Letcher, 2007). The high volume and high purity of oxygen required by Sasol's operations are the main reasons Sasol make use of the Cryogenic Air Separation process of extracting oxygen from air.

2.3.2. Membrane air separation has a clear need for improvement in large scale air separation. The operating range and diversity in the large-scale membrane air separation industry are limited due to the number of available membrane materials that cannot be maintained under aggressive feed conditions (Wang et al., 2011). The membrane air separation industry faces a couple technical difficulties that prevent the membrane industry from growing extensively. These include poor durability, fouling, low separation, and low flux. The most challenging factor, and a major driver for change, is the need for reducing energy usage in all industries (Wang et al., 2011). The high demand in oxygen makes it impossible for Sasol to make use of the membrane air separation process. The process will not be energy efficient and the extraction of oxygen will be much more costly to the company.

2.3.3. Separation by adsorption has been growing at a rapid rate which has some challenges to overcome in order to stay competitive and profitable in all relevant industries. The challenges that the industry face are:

1. Increasing construction and production costs
2. Availability of resources
3. People constraints
4. Higher material costs and longer lead times on material (Sorenson, 2006).

To address the challenges in the air separation process, it is essential to perform well-structured maintenance management and have a structured vision to achieve all production requirements. To ensure less downtime in assets, it is essential to improve maintenance standards in any organization. The separation by adsorption process has some challenges which do not comply to Sasol's operational standards. The oxygen extraction rate is too low and the energy input too high, making process extremely expensive.

Sasol need to stay competitive in the petrochemical industry to retain their market share and even improve the market share to expand the business. The current process that is in use is the Cryogenic Air Separation and, proven through the research conducted, it is not viable for Sasol to move over to an alternative method of extracting oxygen from the atmosphere. The only way of improving on the existing method is to focus on lowering the production costs and delivering the best possible product. The Cryogenic Air Separation process is therefor the best choice to extract oxygen from the atmosphere at the highest quality and at the best price. Implementing a high standard of maintenance management on the cold box will ensure that Sasol have a more constant and reliable production output. Reliability of equipment is the key to most companies' success stories.

2.4. MAINTENANCE MANAGEMENT

Maintenance management has different meanings to different people. This ambiguity may lead to misinterpretation of maintenance activities and lead to catastrophic results in terms of production output. Maintenance can only be correctly implemented once an individual understands the meaning and the consequence of their actions. According to (Telang & Telang, 2010), maintenance can be defined as the process to keep equipment in good condition to perform its intended function. Maintenance can be broken down into two fields which are called technical actions and administrative actions. The technical actions are part of maintenance engineering whereas administrative actions form part of maintenance management.

Márquez (2007), Agrees with the definition put forward by Telang & Telang (2010), and extend the definition by arguing that maintenance management is the management of all assets owned by a company to maximize the return on investment on the specific asset.

Maintenance management is the organizing and planning of all relevant technical resources to repair or adjust assets to perform to their intended functions set out through the company. In a large petrochemical company like Sasol the need for maintenance management practices is extremely high in order to lower input costs and to maximize delivery of products.

A good maintenance management system in any company should make assets available for production. Availability of assets means that, at all times, a production team can expect lights, cooling water, pumps, and whichever equipment that is needed, to fulfill the demand of the production schedule (Bagadia, 2006). If a maintenance management system is performing its intended function for a company, the downtime in assets is minimal and well planned. Maintenance management can be divided into sub categories which are illustrated in Figure 4 below.

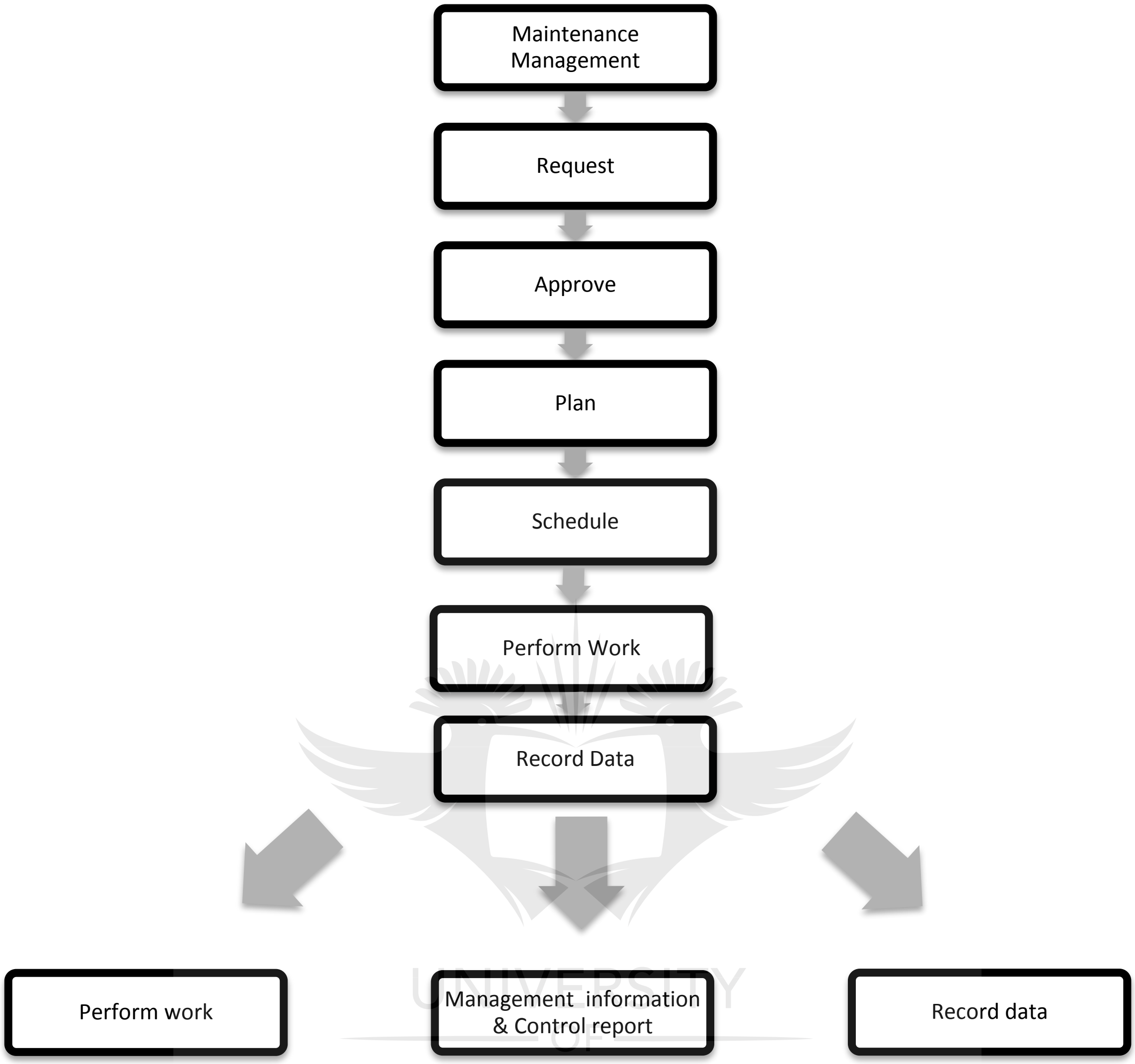


Figure 4: Fundamentals of maintenance management **(Bagadia, 2006)**

Request refers to the request to perform maintenance work and can be communicated in various ways. These include verbal, electronic, and written communication.

Inspections can be conducted after technical personnel identify the inspection method on the cold box and discuss it with the production department. If the production plan allows the inspection to be conducted, it will be planned and executed as agreed by the role players. If any deviations are detected during the inspection, the relevant maintenance personnel will communicate with the production department to plan for the repair process. Approval is required from higher levels of management as the maintenance activities become more complicated and expensive. Day to day maintenance and repairs are authorized at lower levels depending on the impact of the repairs on the process as well as the costs involved. The starting point for effective and efficient maintenance management is to formalize a descriptive maintenance plan. The time frames for the repair durations are crucial to determine the outage time of the cold box. These times are determined by the maintenance personnel who have extensive knowledge and experience in the maintenance environment, especially on the cold box in Sasol. The technical foremen in the different departments conducting the maintenance repair activities are the most appropriate to determine repair durations. It is possible to challenge the cold box downtime but only by relevant Area Managers who are legally responsible for the cold box and who should ensure that the reliability and stability of the cold is high at all times. As soon as the maintenance plan is formalized, the relevant maintenance strategies and techniques can be identified. If maintenance management on the cold box is applied effectively, then according to the research conducted, it is clear that the value of the equipment in Sasol will be higher and more reliable. The core focus of this research is to improve maintenance management of the cold box. This will improve the reliability of the equipment radically.

2.4.1. Maintenance Plan

A maintenance plan is crucial to indicate what needs to be done in a certain maintenance activity, how the activity should be conducted and the timeframe allocated to the activity. A maintenance plan needs to be formalized to determine the material, labour, timeline, and details for the specific maintenance activity that needs to be performed. The plan can be a formal Microsoft Project plan depending on the complexity of the maintenance work to be performed (Bagadia, 2006). The planning for maintenance on the cold box only started in 2012 after the first severe liqued oxygen leak, before 2012 only online inspections was done without detecting internal piping and vesssel leaks. When doing a maintenance repair project like a general overhaul (GO), there is a high number of tasks and activities and Microsoft Project cannot perform its intended function so Sasol use an alternative planning tool. Maintenance schedules form part of the maintenance plan and specifically focus on the sequence of events of the set out plan. Maintenance planning on GO's is controlled by the central planning department in Sasol with the input from all key role players in the repairs that must be conducted. The scope of work is compiled by the subject expert and handed to the planning department to compile a program for execution of the work.

Maintenance schedules can be divided into three categories.

- Priorities – the priority coding that is assigned to each maintenance activity depends on the impact of the equipment that needs to be repaired.
- Job assignment – the jobs are assigned to maintenance artisans or maintenance technicians.
- Follow up – is very important to ensure that the planned activities were executed correctly.

The execution phase of a repair project is where the tasks are executed by the maintenance personnel with the program that is issued to them by the planning department. Maintenance planning on GO's is handled by the central planning department in Sasol with the input from all key role players in the repairs that must be conducted. The scope of work is compiled by the subject expert and handed to the planning department which is an independent division that specializes in planning and coordination of maintenance activities. The more complicated the task that must be executed, the more detailed the executing plan must be. The priorities of maintenance activities are extremely important and are categorized by the criticality of the component on the cold box. The amount of high priority work orders can be an indication of an unreliable cold box as the planning could not be done prior to the repair process. The execution phase of the specified tasks on a cold box repair project are overseen by maintenance supervisors, mechanical foremen, and coordinated by the planning department. The more senior maintenance personnel are utilized to ensure the maintenance activities are performed up to standard and according to the supplied specifications to enhance and improve the reliability and stability of the cold box.

Data should be recorded to provide a detailed equipment history. History on aspects like costing, material that is used in the repairs, equipment identification, and so on. In any company it is very important to know where money is spent and to know what is purchased with the allocated funds. It is also important to identify the amount of downtime captured by the history (gathered during maintenance activities) being conducted by the maintenance team. Management information is needed to present facts to higher management and should include costs, budgets, equipment identification, productivity, and scheduling. Updating equipment history is vital in finding trends in the individual equipment performances. This might help to improve the maintenance strategies of the equipment and to have a history on all equipment (Bagadia, 2006).

The effectiveness of maintenance management can be measured through various methods, but the most commonly used system is the Computerized Maintenance Management System (CMMS). A well-know CMMS program in the petrochemical and manufacturing industries in South Africa is SAP. A maintenance manager does not need to know how to develop CMMSs but they should understand its functionality well to evaluate if the implemented maintenance plan is effective or not (Márquez & Fernandez, 2012). The maintenance plan should be formalized to include all reliability short comings in an organization for continuous improvement of the assets. The focus on reliability in maintenance plans can lead to fewer unforeseen breakdowns and more stable operations. The implementation of a high quality maintenance plan adds value to maximizing the production output, as the equipment is given a more controlled maintenance, through a history that enables future improvement.

2.4.2. Maintenance strategies and techniques

In the maintenance environment it is important to have a clear understanding of the layout of maintenance strategies and the techniques that form the basis of the strategies. The cold box is maintained on a reactive maintenance philosophy (Run-to-Failure). Reactive, proactive and design out maintenance are the traditional strategies commonly known in the industry. Proactive maintenance is strengthened with risk-based maintenance, total productive maintenance, and reliability centered maintenance strategies (Vlok, 2012). The cold box consists of sixteen (16) main equipment, where it can be divided into categories to differentiate what strategy will be most efficient for the equipment in the Sasol environment. An accurate risk assessment needs to be conducted on all main equipment as well as the sub components to determine the impact of a breakdown on the Sasol production and safety environment. The unexpected breakdown on one of the cold boxes in January 2012 lead to in depth failure mode and effects analysis (FMEA). The failure modes are all results of the isolation material that are removed and disposed in the years of service. A full metalurgical report on all failures with recommendations were issued after the repair process of the cold box in 2012. The findings and all learnings helped tremendously with the improvement of the maintenance strategy on the cold box. The probability of future failures is much more controlled as the failure mechanisms is identified but the maintenance strategy is crucial to prevent any unforeseen breakdowns.In figure 5 the maintenance strategies are presented and will be discussed in this section.

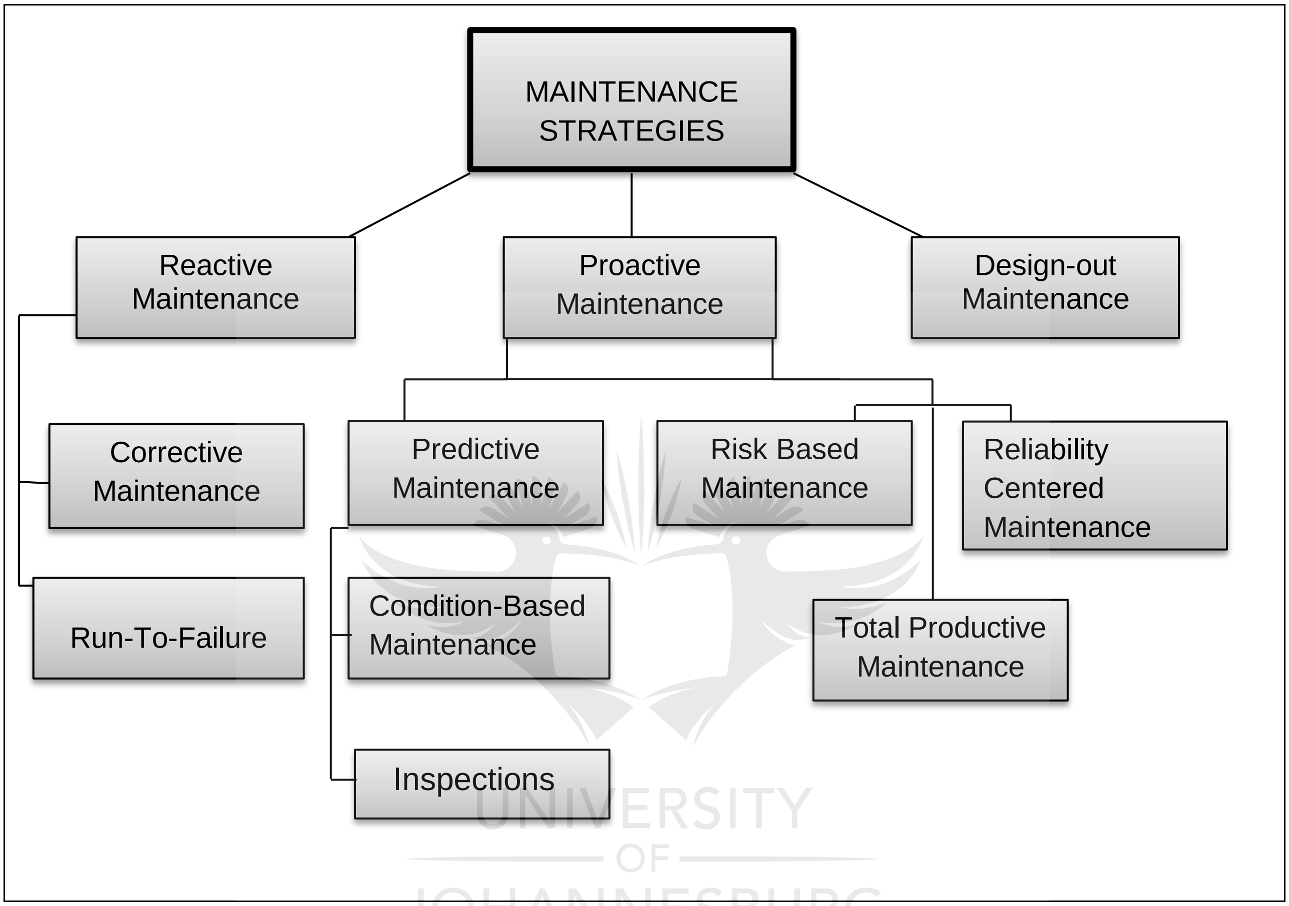


Figure 5: Maintenance strategy tree **(Conradie, 2015)**

The three most commonly-known maintenance strategies are reactive, proactive and design out maintenance. The strategies are used to determine the maintenance task, frequency and sequence. The failure needs to be identified first to determine the impact of the failure on the production plan of the organization. If the risk and consequence classification is done on equipment, one of the three traditional maintenance strategies can be assigned to a specific task (Conradie, 2015). If the risk of production loss and safety impact is great, extremely close attention must be paid to the maintenance strategy to ensure that the value of the maintenance strategy is significant.

2.4.2.1. Reactive maintenance

Reactive maintenance can be divided into Corrective Maintenance (which is referred to as Breakdown Maintenance) and Operate-to-Failure (OTF) (Smith & Mobley, 2008). In Figure 6 below it is illustrated that in Reactive Maintenance has a specific start and end date. The major concern with Reactive Maintenance is that the start date of the repair is unknown and that is why it is called a breakdown. The goal in Reactive Maintenance in many organizations is to reduce the response time and equipment downtime to a minimum. The cold box is currently maintained with an OTF maintenance strategy, but this strategy is very ineffective. The aim of this research is to move away from reactive maintenance and towards proactive maintenance.

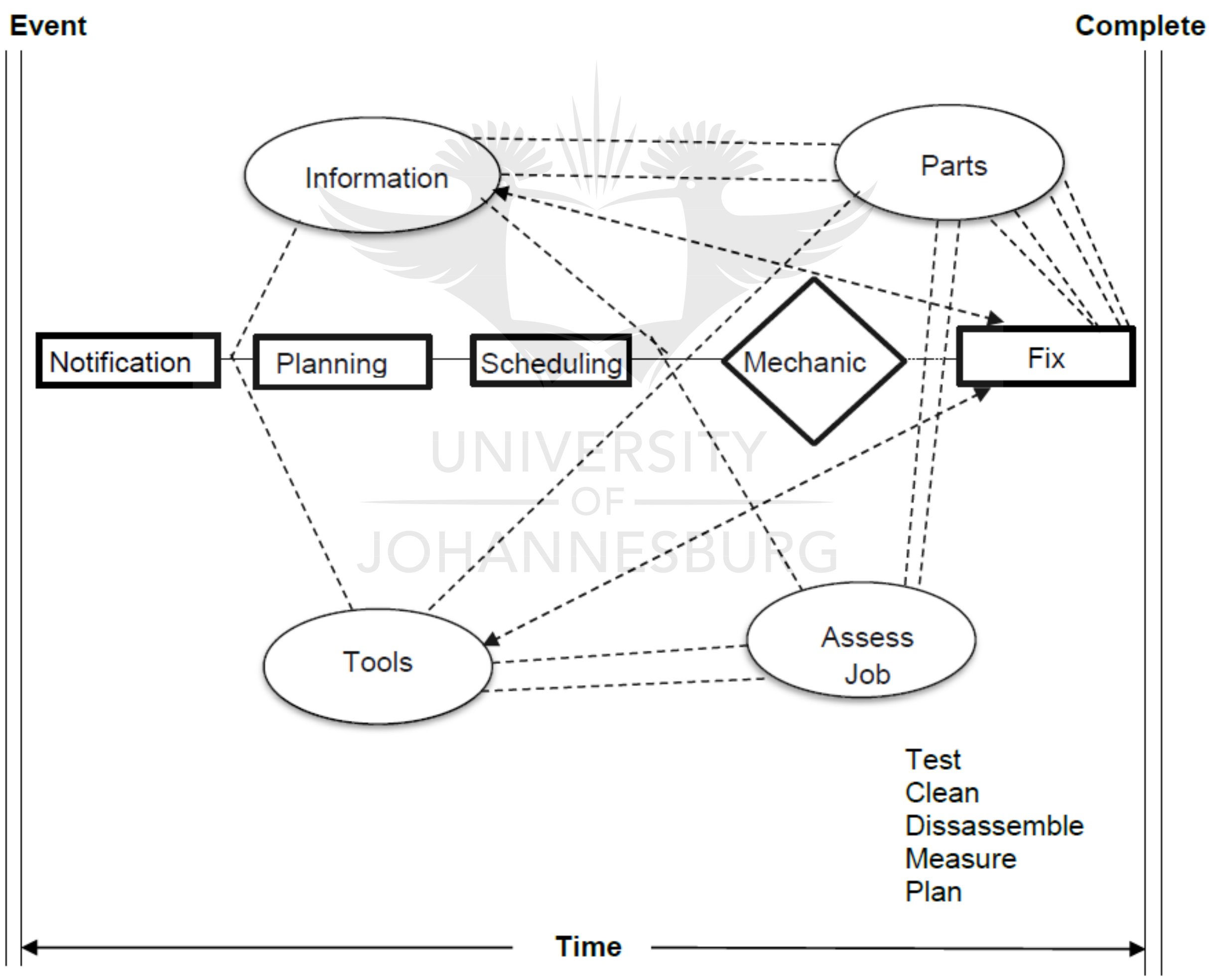


Figure 6: Process flow of a reactive maintenance task (Smith & Mobley, 2008)

Corrective maintenance or breakdown maintenance refers to the unexpected and unplanned breakdowns of equipment that can potentially cause productions losses. These are the least favorable maintenance tasks in an organization. The main focus of these tasks is to repair the affected equipment in the shortest possible time. The effectiveness of the repair is determined by the functionality of the system after the repair. The system should operate at an acceptable level (Mobley et al., 2008). Reactive maintenance is ineffective and costly and is considered to be bad engineering practice. There are two factors that contribute to the ineffectiveness of the breakdown maintenance process. There is poor planning due to planned personnel on an interrupted weekly schedule. And there is the incomplete and rushed repair process that is sometimes followed, due to very little turnaround time, which can result in a recurring failure on the equipment (Mobley et al., 2008).

The Operate-to-Failure maintenance technique is an established maintenance strategy and it is deliberately allowed to operate until failure. The equipment that is typically on an Operate-to-Failure strategy is the equipment that does not impose major production losses or safety threats to an organization. An example of such equipment is a light bulb (Smith & Mobley, 2008). The repair processes followed are unplanned and costly. This is similar to corrective maintenance, except that there is a plan in place for when the repair should be conducted. The spares are already identified before the failure occurs to reduce the production impact on an organization (Mobley et al., 2008).

2.4.2.2. Proactive maintenance

Proactive maintenance is time-based maintenance that is planned periodically irrespective of the condition of the equipment (Mishra & Pathak, 2012). In the reliability engineering environment, it is critical for engineers to plan remedial work well in advance to ensure that an asset is available as long as expected from the production team. The basic idea behind proactive maintenance is that the asset should be repaired before it fails its intended function in an organization. The purpose of proactive maintenance is to determine:

- Routine maintenance of tasks through visually inspect and test equipment
- Spare part requirement
- Standard tasks covering routine work
- Inspection and overhaul schedules for all critical equipment

- Manpower requirement as per scheduled requirement (Mishra & Pathak, 2012).

If the steps above are followed correctly the number of breakdowns will decrease and the availability of the equipment will start to increase. The best way to describe proactive maintenance is from the illustration in Figure 7. In the figure, point P indicates the point where potential failures might occur and point F indicates the point where a functional failure might occur. The repair of should be done in the P-F range before the breakdown happens (Plucknette, 2010). The mean time between failures can be determined by active online monitoring techniques which will be beneficial for a reliable maintenance strategy with correct decommissioning intervals. The cold box only failed once since it was constructed so it is difficult to determine an accurate MTBF with the history of the equipment. The expected number of breakdown can be theoretically calculated by conducting an FMEA on the critical components of the cold box but due to the criticality of the cold box and the limited amount of availible information it is not always possible to conduct a succesfull FMEA. The expected breakdown cost is then calculated taking into consideration the production loss, labour, material and engineering input. In cases where breakdown occurs before point F in Figure 7, the maintenance strategy should be revised and all failure modes should be considered.

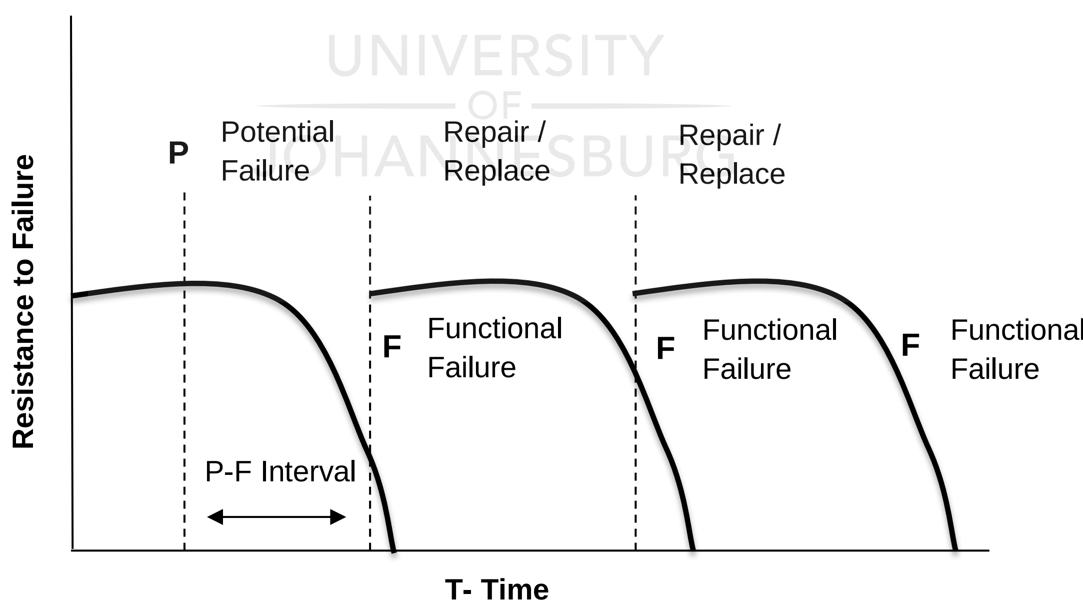


Figure 7: P-F curve for proactive maintenance **(Plucknette, 2010)**

Proactive maintenance can be regarded as planned scheduled maintenance. The cold box is currently maintained on a black box approach which is why it is not always possible to predict when the equipment, which make up a critical component of the Sasol factory, will fail, This research will help to move away from breakdown maintenance and develop predictive maintenance.

2.4.2.3. Design out maintenance

Design Out Maintenance (DOM) is to create a maintenance-free environment in a period of time as the history on a specific asset becomes available. In DOM, it is critical to determine the root cause of a failure to eliminate the failure in future and to completely eliminate the failure mechanism from the asset. DOM follows a root cause elimination process to create high reliability equipment through an engineering design change to its components (Disselkamp, 2013). In cases where maintenance alone is not sufficient to resolve a failure on an asset, DOM is used to permanently resolve the root cause of the failure (Anon., 2014). DOM on the cold box is ideal but not always feasible due to the complexity of the system. To ensure that the cold box is the most reliable equipment, DOM will be the solution if it is possible to remove all failure elements from the system but the market is limited in terms of cryogenic equipment.

2.4.2.4. Risk based maintenance

Risk Based Maintenance (RBM) helps to design an alternative strategy to minimize or eliminate risk as a result of breakdown and/or failures in any organization. In cases where an RBM strategy is utilized, the risk of possible failures are analyzed based on the probability and consequence of the failure (Sarkar & Behera, 2012). The RBM process consists of four steps which are listed below.

1. Identify the scope of the breakdown or repair
2. Assessment of risk
3. Evaluation of risk
4. Perform maintenance planning (Krishnasamy et al., 2005)

Critical equipment can be identified by means of the level of risk the specific equipment opposes to the organization and from there the critical spares list can be compiled. Optimal spare holding analysis is conducted to determine the necessity of the certain critical spares identified by the risk classification. The spares are ordered prior to the repair process as an act of pro-activeness. Maintenance on the equipment is prioritized according to the risk level of the equipment, which helps to minimize the overall risk of the entire organization. RBM has proven successful in companies in increasing the reliability of the equipment in the organization and reduces the cost of maintenance and the cost of failure (Sarkar & Behera, 2012). RBM together with reliability centered maintenance is the key to success for the cold box and will be implemented to identify critical equipment on the cold box.

2.4.2.5. Total productive maintenance (TPM)

TPM is a well-structured approach of equipment maintenance which involves all maintenance personnel focusing on minimizing and eliminating equipment breakdown and defects that can lead to major production losses in an organization (Agustiady & Cudney, 2015). TPM is a systematic approach which is used to improve quality and production systems. TPM has five goals in any organization and some texts call them pillars.

1. Improving maintenance effectiveness and efficiency
2. Maintenance prevention through early repair management
3. Improving the effectiveness of equipment
4. Improve employee skills of the entire workforce in providing training
5. Ensure operators are involved in maintenance repair processes (Wireman, 2004).

All employees should be included to ensure effective maintenance activities. The main aim of implementing TPM is to achieve improved productivity by investing in maintenance activities to reduce production losses.By implementing TPM, the following losses can be prevented in an organization.

1. Idling
2. Quality of work
3. Setup and adjustment
4. Breakdowns
5. Rework
6. Minor stoppages (Agustiady & Cudney, 2015).

The TPM process has four main objectives in an organization and they are:

1. Total involvement of all employees
2. To use a hand-on approach
3. Improvement of the organization's competitiveness (Agustiady & Cudney, 2015)
4. Lastly the four-phase approach is what concludes the entire TPM process. Below is a figure that demonstrates the phase.

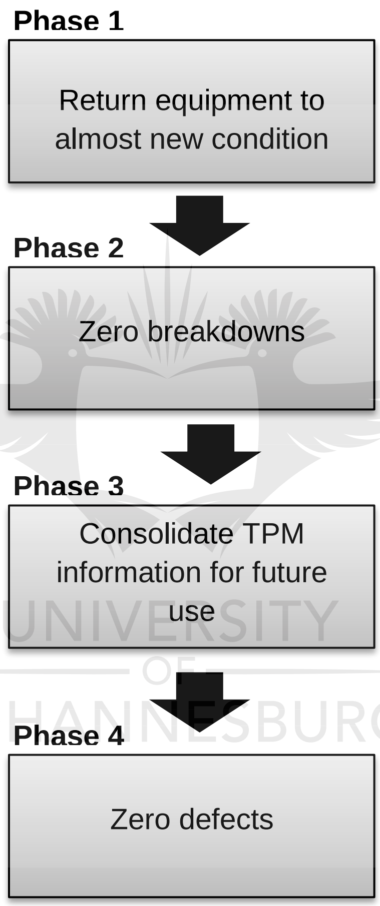


Figure 8: TPM phases **(Agustiady & Cudney, 2015)**

Phase one focus on restoring the equipment to its original integrity or as close as possible to that. Phase two focuses on effective and efficient maintenance to ensure no breakdowns will follow. In phase three, all information gathered for future improvement on the entire TPM process is assessed. If all three phases are conducted at high level, the last phase will be that zero defects will be present in an organization (Agustiady & Cudney, 2015). In any industry, all organizations strive to be at the point of zero defects to ensure safe and stable operations. This will make the organization highly competitive and cost effective.

2.4.2.6. Reliability centered maintenance (RCM)

Asset reliability in any organization is the key to successful and predictable operations and ensures that an organization has a competitive advantage in their field of expertise. Reliability Centered Maintenance as a technique for effective and efficient maintenance will be discussed in depth under 2.7. when the concept of reliability made more clear. RCM is the solution to the research problem statement, to move from the traditional black box approach of doing maintenance to the point where breakdowns are more predictable and can be scheduled in advance.

2.5. RELIABILITY

2.5.1. History of reliability

History for reliability engineering can be traced back as far as World War II, where the Germans first introduced the reliability concept on the V1 and V2 rockets to improve the reliability on this equipment (Dhillon, 2006). In 1950, the United States department of defense established a dedicated committee for reliability, and in 1952 this committee was reformed into a permanent group called the Advisery Committee on the Reliability of Electronic Equipment (AGREE). The committee released its first report in 1957 (Dhillon, 2006). In 1962 the first master's degree program in system reliability engineering was started in the United States (Dhillon, 2006).

Maintenance was undertaken only reactively until 1950 and thereafter proactive maintenance was implemented. Late 1950's proactive actions were put in place to prevent the same failure to resurface. Maintenance and the planning behind the scenes became much more sophisticated after 1960, to the point where it can be predicted when a failure might occur and proactive maintenance measures can be put in place. See Figure 9 the emerging strategies for maintenance management from the year 1930 until the year 2000.

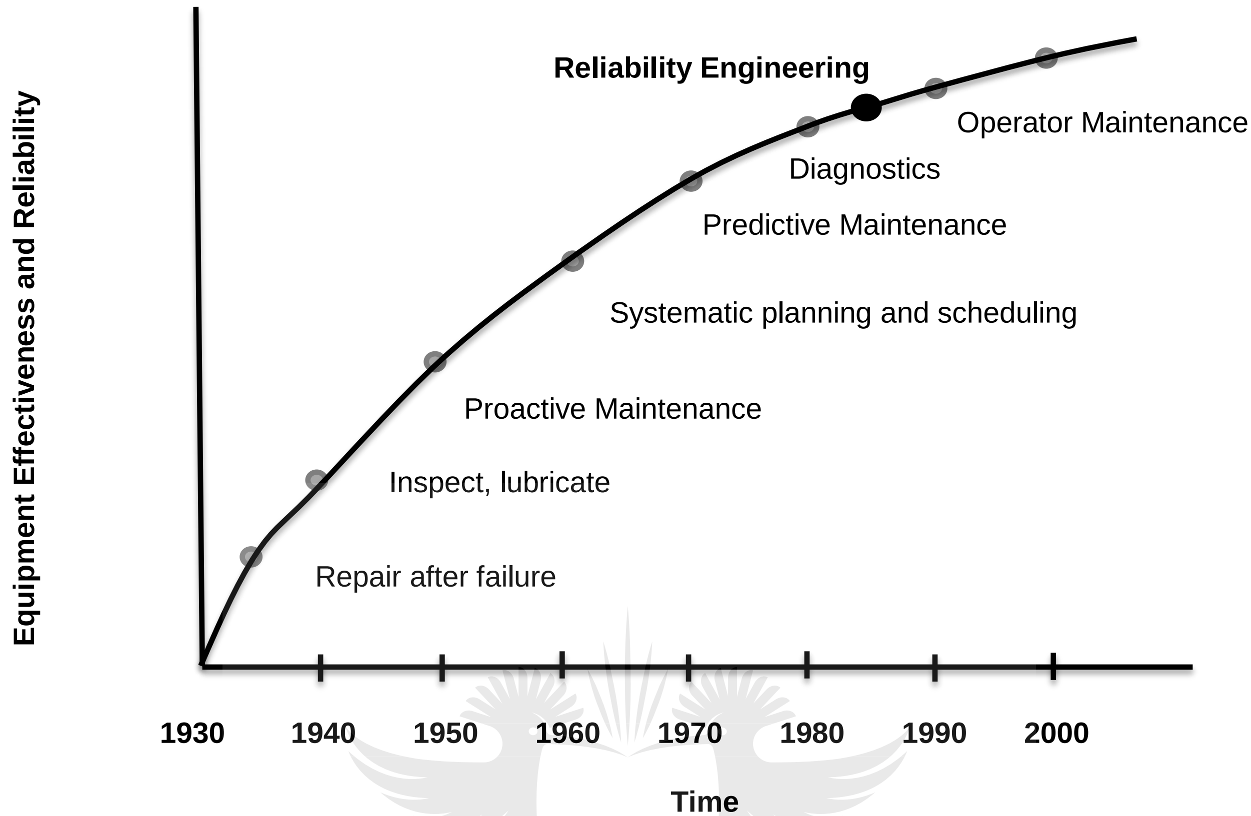


Figure 9 : Emerging strategies for maintenance management **(Campbell & Reyes-Picknell, 2006)**

2.5.2. Why is reliability important?

The importance of a reliability maintenance system in any organization can be evaluated and linked to the success in an organization. The discipline with which an organization improves the safety performance is related to the probability of failures and can be a measure of the importance of a reliability system in an organization (Dubourg & Sudret, 2015). Due to unforeseen occurrences and failures, there are several constrains of financial difficulties in the maintenance environment. A major concern in organizations is that the users and supervisors struggle to apply reliability maintenance techniques on new and improved assets. New equipment does not have a failure history whereas equipment that is in service for a certain period of time has a maintenance and performance history (Szybka et al., 2014). Organizations need to perform asset reliability techniques to improve competitiveness in the industry. There are five main factors why asset reliability on equipment is critical:

1. To ensure customer satisfaction

Reliable assets perform as per identified production output and deliver results every time. Unreliable assets negatively influence customer satisfaction. To ensure customer satisfaction, the need for asset reliability is important. Customer satisfaction is crucial for the existence and sustainability of any organization.

2. To improve and maintain an excellent reputation

If organizations' assets are reliable, it is more likely that the environment will have a more favorable reputation in the industry. The market share of products and services with a good reliable history and reputation is notably higher than unfamiliar brands.

3. Operating and maintenance cost

Asset performance that does not meet organizational standards and production outputs can be costly and the maintenance will be more expensive. Asset performance needs to be effective and efficient to reduce overhead costs. Operational and maintenance equipment reliability results in improved cost and profit performance, less environmental and safety incidents, as well as a reduction in management involvement.

4. Competitive advantage

Organizations need to achieve a sustainable competitive advantage in the market, which allows organizations to outperform their competitors. This will result in increased profit and a venture that is sustainable. Reliability and availability of assets are integral to a highly competitive organization and should be maintained at a high level in any organization.

5. Repeat business

Customers need to experience well-structured and organized business practices to satisfy their needs in a timely manner to willingly give future business to an organization. Reliable assets can make this a reality and can have a positive impact on the organization (Gulati, 2013).

2.6. RELIABILITY- AND QUALITY MANAGEMENT

2.6.1. Reliability management

Maintenance management can have different meanings to different people. This might lead to misinterpretation of maintenance activities and lead to catastrophic results in terms of production output. Maintenance can only be correctly implemented once an individual understands the meaning and the consequence of his actions. According to Telang & Telang, (2010), maintenance can be defined as the process to keep equipment in good condition to perform its intended function. Maintenance can be broken down into two fields which are called, technical actions and administrative actions. The technical actions are part of maintenance engineering whereas administrative actions forms part of maintenance management. To perform market leading reliability maintenance practices on the cold box, it is of utmost importance to know what the term reliability means and how it relates to the equipment under investigation. To improve reliability on the cold box the planned production output needs to be as close as possible to the actual production output. This means that the cold box performs to its intended function. If the current operation of the cold box is not up to Sasol standard, it must be investigated why there is a deviation, which needs dedicated reliability personnel to investigate. The investigation need resources and will be costly to perform. If the deviation is severe the impact will justify the investigation.

Listed below is a comparison of three authors' definitions of reliability.

- *Yang:* "In technical terms, reliability is defined as the probability that a product performs its intended function without failure under specified conditions for a specified period of time" (Yang, 2007)
- *Murthy, Rausand and Osteras:* "The ability of a product to perform required functions, under given environmental and operational conditions and for a stated period of time." (Murthy et al., 2008)
- *Tortorella:* "Reliability is the ability of a system to perform as designed, without failure, in an operational environment, for a stated period of time." (Tortorella, 2015).

The common elements that can be identified in all authors' literature is the intended definition of function, usage and environmental conditions, definition of satisfactory performance, and a specified period of time (Kapur & Pecht, 2014).

Reliability means that equipment needs to perform a specific function under specified conditions in a given time frame without any failures. In all maintenance processes it is essential to verify the reliability of equipment for the prevention of unexpected equipment breakdowns. Sasol and all industries that are successful in production and maintenance activities have one common goal and that is stable and reliable equipment to enhance production output.

Here are five essential processes to evaluate the reliability of equipment:

1. Determine the required performance of the equipment under all environmental conditions
2. Analysis of the equipment to determine its capabilities
3. Variation analysis to establish complete variability
4. The process of fault mode analysis to determine availability
5. A process to obtain a certain reliability value over an appropriate time in using the above steps (Mishra, 2006).

Reliability in a broad sense is highly focused on failures and the prevention of unexpected failures occurring in operational industries. It is of utmost importance to understand the root cause of the failures in order to improve on the reliability of an equipment or system (Green, 2007). Reliability is a specialized field which has improved tremendously over the past couple of decades in order to ensure more stable operations in companies all over the globe (Campbell & Reyes-Picknell, 2006). In the Sasol environment there are additional equipment monitoring systems that can be investigated and implemented to improve the reliability on the cold box. The five additional systems are:

1. Additional online monitoring equipment
2. Online non-destructive examination to determine the health status on the cold box
3. Active monitoring by the production personnel by implementing additional plant walks and inspections
4. Thermal scanning of equipment and piping on the cold box

5. Risk based inspection on critical equipment to minimize risk of breakdown.

The five systems under investigation will be included in the chosen qualitative research method to test the value that the systems will add to the improvement of the reliability. These systems will be implemented on critical components identified by a risk classification process conducted by the maintenance management team and subject experts in the reliability environment.

2.6.2. Quality management

Quality can be defined as the ability for an organization to conform to the requirements of clients and users and to comply with their needs and meet their expectations. If an organization's quality of products and services improve, the norm is that a reduction of costs will follow (Burtis & Bruns, 2014).

The efficiency and effectiveness of an organization's quality management system is very important to improve the quality and operational performance of an organization. The impact of quality management does not reflect severely on business performance, but influences business performance positively (Leong et al., 2014).

In the petrochemical industry the competition is very great and to stay competitive in the market many organizations tend to turn to total quality management for continued improvement on product and service quality. Total Quality Management (TQM) is a philosophy that most organizations use to measure and continuously improve on quality in all products and services. TQM focuses on five basic steps to improve quality in an organization. The five steps are quality planning, quality process, quality control, quality assessment and lastly quality improvement to close the loop (Burtis & Bruns, 2014).

TQM is a quality system which an organization implements to ensure high quality products and services delivered through the organization. There are nine key elements that an organization needs to have in place for the quality system to meet expected quality objectives.

- Equipment
- Customer service
- Process improvement

- Documents and records
- Organization
- Information management
- Occurrence management
- External and internal assessment
- Purchasing and inventory (Burtis & Bruns, 2014).

Studies that were conducted on quality management indicated, organizations that lead in the TQM field proved to be positively related to numerous attributes in the maintenance field. Below is a figure that indicates the positive influence of TQM on an organization and the proposed research model of the relationship between TQM practices and performance measures (Sadikoglu & Olcay, 2014).

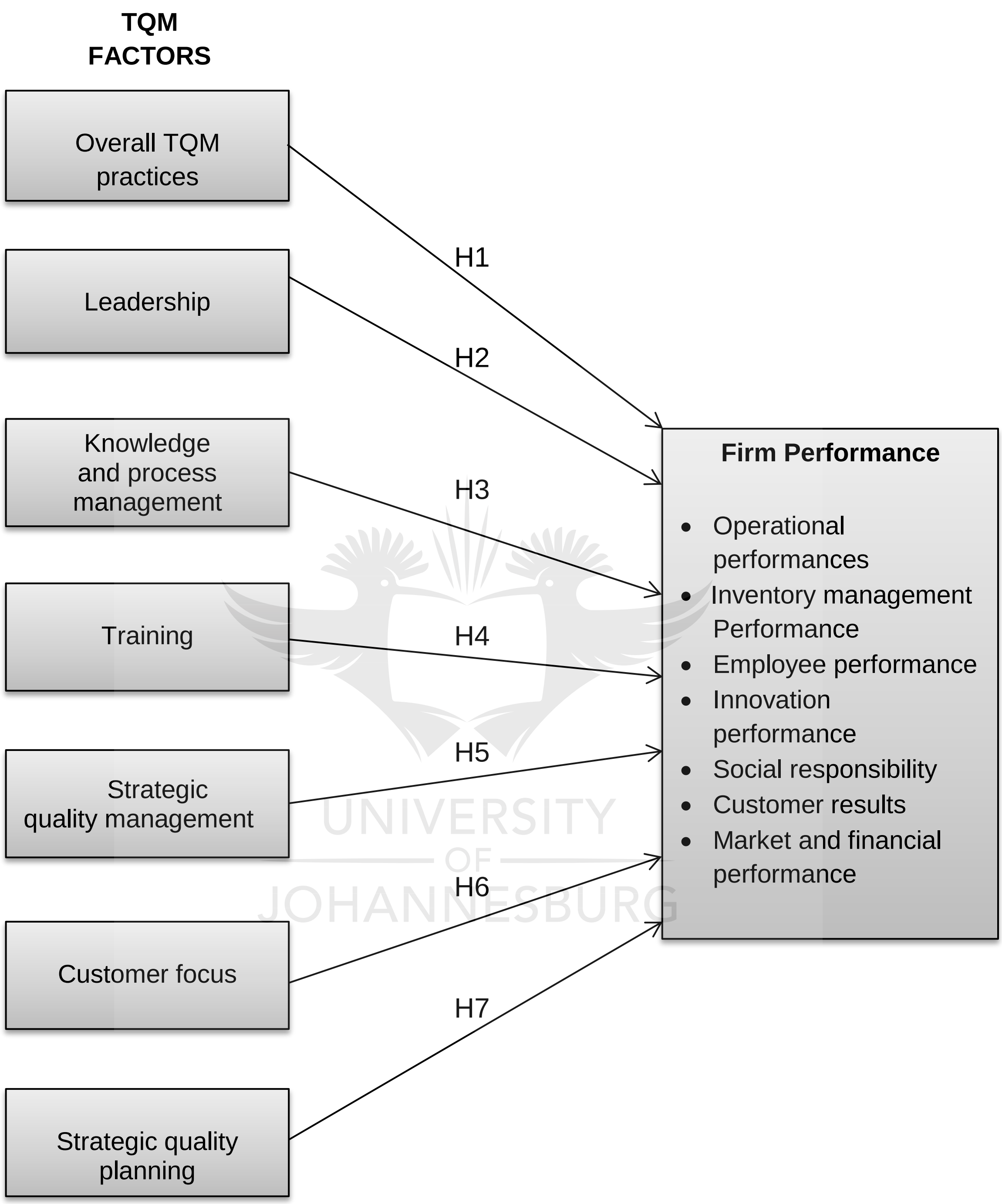


Figure 10 : The proposed research model **(Sadikoglu & Olcay, 2014)**

Quality management is the core of any organization's performance and ability to be competitive in its given area of expertise. The quality of products that are presented to possible customers should be attractive and of outstanding quality. The quality of the product as well as the service can be the factors that convince the customer to return for future business. The improvement in service quality and maintenance activities performed on the cold box are crucial to implement high quality guidance and specifications. A maintenance inspection check list is an example of guidance provided by the maintenance team to ensure that all maintenance activities are performed as per agreed specification.

The market share in any organization is very important for the growth and sustainability of the organization. The core product that is produced from the cold box is oxygen and if the quality is low and deviates from the specification, it cannot be utilized for its intended function. This means that the product must be recycled and recreated which is a total waste of energy and resources. Reliability of all equipment is important and as is the knowledge of the production trend of the equipment and the history of the equipment. It is thus essential to move away from the traditional approach of doing maintenance and focus on predictive maintenance to ensure stable and reliable operations.

2.6.3. Difference between quality- and reliability-management

In the cold box there are numerous items that cannot be maintained frequently. It is incredibly important that the equipment and piping that are used should be of the highest quality available on the market. The critical equipment should be listed and analyzed fully to ensure that the downtime on the cold box is kept to the minimum. The cold box production plan does not allow it to be offline for the duration it takes to do any repairs on the cold box. Using high quality material to repair the cold box makes the reliability factor higher. This prevents unplanned downtime of the equipment and unnecessary production losses.

According to Mishra & Sandilya (2009), it was found that during failure analysis on equipment in certain industries that high quality equipment, has less number of failures and that low quality equipment has more frequent failures. The higher the quality on equipment, the better the reliability of the equipment is in any industry. If the reliability is high, it adds to the value of the equipment which gives a competitive advantage to an organization in today's technologically advanced industries. The reliability of equipment is evaluated through the reliability of all the parts of the specific equipment, it is of utmost importance that the quality of all parts needs to be of a high standard. The higher the quality of equipment the more attention the equipment enjoys from customers and maintenance problems are minimized of the product. It is critical to complete a maintenance inspection checklist to ensure that all equipment was fitted correctly and according to a standard specification supplied by the maintenance department of Sasol.

Quality and reliability of equipment in an organization is closely related to each other. In numerous cases when failures occur suddenly and unexpectedly it can be found that the equipment under investigation is of very poor quality. To improve on the reliability of equipment to perform to a specified production output in a specified time it is wise to improve on the quality of the equipment installed in critical areas in a facility. This research will focus on improving the quality of maintenance on the cold box and the improvement on the quality will automatically follow if the required steps are followed.

2.7. RELIABILITY-CENTRED MAINTENANCE

2.7.1. Maintenance and Reliability Centered Maintenance

Reliability Centered Maintenance started when a proactive maintenance plan was developed for the Boeing 747 airplane in the 1960s by the maintenance steering group. For mainenance in the RCM process,consideration is not only given to what can be done, but also wo what should be done. To facilitate the RCM process seven questions should be asked to complete the process.

1. What are the functions and performance standards of the asset in the operating environment?
2. How does the asset fail to perform its intended function?
3. What causes each functional failure?
4. What happens to the process when each failure occurs?
5. How does each failure affect the process and how does it matter?
6. What can be done to predict and prevent each failure?
7. What can be done if the relevant proactive task cannot be done (Tinga, 2013)?

The first five steps in the process are the Failure Mode, Effect and Criticality Analysis (FMECA). The last two steps are where the failure mechanism is established and the suitable maintenance task is identified and allocated to the relevant activity to perform effective maintenance (Tinga, 2013). If the five questions are answered correctly and with the desirable input from the relevant stakeholders, they can be the answer to the research question at hand. The nature of the maintenance being conducted on the cold box make it difficult to flawlessly answer the five questions, but the research will improve the quality of the answers and thereafter the improvement phase can take place.

2.7.2. The RCM principles

The RCM process consists of four principles that stipulate the characteristics of the process. Below are the four principles.

1. Maintaining the system function is the first step in the RCM process. This step requires that the desired system outputs must be identified and ensure availability on all critical equipment in an organization.
2. Identification of the failure modes that can cause a functional failure. The information gathered in this step can be used to ensure that the operational and design parameters are correct. This will determine if the system needs to be modified or if a maintenance plan will be sufficient for the maintenance on the system.
3. Prioritizing and categorization of functional failures. Step three needs to ensure resources are used efficiently and cost effectively. The correct utilization of resources can lead to enormous long term cost savings and can improve on the maintenance quality of an organization.
4. Selection of the applicable and effective maintenance tasks for the identified high priority items. The correct allocation of resources to the high priority tasks can have a positive effect on production and will improve the availability of equipment for the production team (Ben-Daya et al., 2009).

2.7.3. The RCM process broken down into steps

The RCM process can be divided into three steps and can differ in some organizations. Decribed below are the basic steps of the RCM process.

1. Selection of the system and the collection of the relevant data
    - Collect all relevant data
    - Identify and define system boundaries
2. Develop a clear understanding of the entire system to be worked
    - Identify and define all sub systems
    - Functional tree
3. Identify and define all system functions and functional failures
    - FMECA
    - Data capuring and processing
    - Detailed risk analysis (McMillan & Ault, 2014).

To understand why RCM is important in any maintenance environment, it crucial to know how to use RCM as a tool to improve maintenance activities in an organization.

2.7.4. RCM utilized as a tool to improve maintenance activities

The various goals in the RCM process are the improvement of maintenance activities in any production driven industry. The RCM process is utilized as a tool to improve maintenance activities and techniques in and organization. The most important goals of the RCM process are:

- To help determine the best possible maintenance program available for the given operational specifications
- To help determine the best maintenance efforts in terms of operational efficiency and cost effectiveness for an organization
- To keep the focus on the most crucial functions in an organization
- To ensure that no or limited unnecessary maintenance functions is performed by the maintenance team (Ben-Daya et al., 2009).

The RCM process utilized as a tool in the maintenance environment focuses on system reliability at the lowest possible cost. Cold box GOs have a set allocated budget and the objective of the maintenance management team is to complete the project within five percent over the allocated budget. The reliability and cost effectiveness of assets is very important in any organization, but the safety and the environmental impact of the organization is equally important. It is crucial for any organization to focus on all aspects of success and not only on selective key aspects (Ben-Daya et al., 2009).

The benefits of utilizing the RCM process as a tool in maintenance have a significant impact on the organization. The following benefits can be identified from the RCM process:

- Cost savings
- Moving from time-based to condition-based work
- Using fewer spare parts
- Improvement on safety and environmental conditions in the workplace
- Doing less work at a higher efficiency
- Improvement of skills and technical knowledge (Ben-Daya et al., 2009).

2.8. SUMMARY

In the last six decades, maintenance philosophies have moved from reactive maintenance to pro-active maintenance. Reactive maintenance is known as firefighting mode maintenance, which negatively impacts the production output of an organization.The cold box is a critical equipment in terms of supplying oxygen to the Sasol CTL process, it is of utmost importance to ensure that the best possible maintenance philosophy is followed. The core focus of this research is to identify the key areas of ineffective maintenance and implement a more effective maintenance strategy. Ideally, Sasol want to move from a black box maintenance approach to a predictive maintenance approach to ensure a more reliable and stable production environment. The review of literature in this chapter has shown that certain research has been done concerning maintenance and reliability management on assets in organizations and especially on the cold box in Sasol. Reliability can be improved with a well-thought data collecting system, recording and well-structured action plan. Sasol has its unique maintenance management style which is implemented to ensure that the cold box is reliable and stable. To improve the current maintenance management system, a qualitative data gathering method is the answer. This will direct the researcher to see what data is available and what is needed to improve on the existing system. The comparison of old and new data will highlight the shortcomings in Sasol. Qualitative data gathering methods is an effective and safe way of gathering data in a multidisciplinary environment like Sasol. Vital information, resources, and methods are identified in order to attempt a solution to the problem as identified in Chapter 1. Chapter 3 will present the research methodology in more detail.

CHAPTER 3

METHODOLOGY

3.1. INTRODUCTION

The cold box is a critical component in the Coal To Liquid (CTL) process in the petrochemical industry. The petrochemical industry is highly competitive and therefor requires a well-planned and organized environment to expand business for competitiveness. The cold box in Sasol plays a vital role in the factory's production schedule, which is why the equipment should be as reliable and stable as possible for accurate production schedules to be achieved. In Chapter 2 three different air separation processes were identified and it was discovered that the existing air separation process is the most suitable for the Sasol environment, due to its adaptability to the required specification. The literature focused on improving the reliability of the cold box, due to Sasol's dependability on the oxygen output of the system. The traditional black box approach of conducting maintenance is under investigation and must be replaced by a predictive maintenance strategy to determine breakdowns and equipment failures before they occur. Maintenance management is extremely important to ensure that all newly implemented strategies are conducted flawlessly.

The methodology will guide the research conducted in the literature review in the direction of the research question. The methodology describes the extensive philosophy supporting the chosen research method which is this study is a qualitative method. The methodology should reflect the academic basis for all choices of research methods that the researcher makes.

In Chapter 2, an extensive literature review was done on ways to improve maintenance methods and management, thereby improving the reliability of the cold box. The literature review emphasized the importance of reliability engineering and how maintenance is managed in companies similar to Sasol in size. It is important to maintain the equipment proactively to ensure safe and stable production operations in Sasol

The primary focus of this research is reliability engineering management as it relates to the cold box in the SCI environment. The cold box in the SCI environment is an important part of the equipment in terms of supplying an average of 1 428 200 kg/h oxygen to the factory as per SCI production demand. The cold box is designed to fulfill the Sasol factory production requirements and specifications.

3.2. RESEARCH DESIGN

This study entitled "Reliability engineering management in the petrochemical environment: The Air Separation Unit" is a qualitative investigation that attempts to collect existing information about the cold box in the Sasol environment. The key reason for doing qualitative research in a specific environment is to investigate and become more knowledgeable in the industry and equipment at hand of the researcher's interest in order to deliver a detailed description (Trochim et al., 2015). This study will emphasize the importance of the cold box in the Sasol environment and how the lack of well-structured maintenance management can affect the reliability of the equipment in the factory.

The research would utilize a descriptive research method in the conduct of the study. Descriptive research is a method used to obtain information relating to the current status of a defect or occurrence to describe "what exists" within the given variables or conditions of the situation. The two most common types of descriptive research tools are questionnaires and observation (Koh & Owen, 2012). The use of observations from experience in the Sasol oxygen environment will derive a personal explanation of the answer to the research problem.

Selecting an accurate research method to deliver the research objectives is not to be compromised. In order to accomplish the purpose of this research, there is one basic research problem that needs to be defined and analyzed in the Sasol environment. An attempt to define, analyze, and solve this research problem has brought out some important questions:

1. Do the maintenance personnel in the Sasol factory understand how to implement maintenance strategies?
2. Do Sasol maintenance personnel know how to effectively apply maintenance management to improve equipment reliability?

3. Are the technical training needs both identified and available to improve the maintenance personnel's skills to effectively manage maintenance in the Sasol oxygen environment?
4. Does the multidisciplinary team that execute GOs in Sasol understand their roles and responsibilities in terms of improving the reliability on the cold box?

These research questions are the core of the qualitative research at the Sasol Secunda oxygen environment. Validation of the research outcomes is proven against theories and the studies of the Sasol Reliability system.

3.3. DATA COLLECTION METHOD

The data collection method must clearly indicate the academic basis of the choices of research methods made for the mini dissertation. Words like 'was interested in' and 'thought so' are not sufficient for a mini dissertation. There must be sound academic reasons for the selection of a certain data collection method.

3.3.1. Questionnaires

If the intended research question requires that the researcher collect standardized information that is comparable from a number of people, using questionnaires is the best research method gathering data. Questionnaires can be used to collect quantitative and qualitative data. This qualitative research tool is used to gather descriptive and qualitative data on the current maintenance management process on the Sasol oxygen environment's cold box. The survey is developed to complement and support the cases investigated in this study.

The questionnaire was designed for the Sasol oxygen environment, and more specifically for the cold box, to determine the key factors that can be altered to improve maintenance management of the cold box. Improving maintenance management of the cold box it means that the reliability of the equipment is higher and the production output much more stable and predictable. To further validate research findings, questionnaires were administered to experts in all relevant different departments. Questionnaires were distributed to six different departments working on the GO that have extensive knowledge in the study field and will contribute to the research question's answer. The departments are Mechanical, Instruments, Production, Metallurgy, Inspection, and Electrical. The the professions targetes in the questionnaires are area managers, foremen, supervisors, engineers, and process experts. Three questionnaires were distributed per discipline to determine an accurate average.

A well-structured questionnaire should contain the following types of questions:

1. Factual questions
2. Opinion and attitude questions
3. Information questions
4. Self-perception questions
5. Questions about actual past or present behaviour
6. Projective questions
7. Standard of action questions (Connaway & Powell, 2010).

The idea of the questionnaire is to be as accurate as possible and uncomplicated so participants can fully understand what to do. The following principles are important in developing a questionnaire:

1. Each question or item should only express one idea
2. Avoid jargon, abbreviations and colloquialisms
3. Use simple language and expressions
4. Word your questions positively
5. Avoid leading questions (Connaway & Powell, 2010).

The Golden Rule for designing an effective questionnaire is to keep all these five principles in mind, and think: "What do I want to achieve with the answers of the questionnaire?" (Anon., 2015). The answers of the questionnaire must be confidently analyzed and necessary action is required to solve the research question. The design of the questionnaires was done with the input of the maintenance management team that frequently works on the cold box and has an extensive amount of experience of the equipment. An accompanied questionnaire letter, with samples of the survey questionnaire adopted for this research is shown in Appendix A.

3.3.1.1. Instrumentation Department

The Sasol Oxygen Instrumentation Department focuses on the maintenance and reliability of control valves, pressure indicators, temperature indicators, level transmitters, level indicators, rotation meters, flow transmitters, orifice plates, and the control system in the control room that remotely control the entire oxygen production operations. The Instrumentation Department fulfills an important role in the entire Sasol environment as the department is involved in the flow and control of all processes in the factory. In terms of the research question, the Instrument Department can contribute to the improvement of process flow and the reliability of all the equipment mentioned above.

3.3.1.2. Production Department

The Sasol Production Department is like the metaphorical drivers of the bus. The production schedules for the factory are controlled by this division. Technical departments should focus on supplying a stable and reliable plant to ensure that the production schedules are reached. The production team’s main responsibility is to ensure that the plant operates within agreed parameters and considers the condition of all critical equipment. It is critical to ensure that the set out production schedule is reached at all times. The production team’s feedback on plant stability and breakdowns is critical for the improvement on equipment reliability.

3.3.1.3. Metallurgical Department

Metallurgy is a specialized field of expertise which enables the maintenance management team to determine the behavior of different ferrous and non-ferrous metals. The metallurgical department can determine the mechanical properties, diffusion coefficient, thermal, electrical conductivity, etc. of the defective material. This information can help the maintenance management team to determine the failure mechanism that caused the breakdown in the different material. If the failure mechanism is known, the maintenance strategy can be adjusted (Weiss, 2013). The metallurgical department renders a service to the maintenance management team in Sasol. The input of the metallurgical department with the questionnaire can be helpful to improve the equipment design in terms of material for construction.

3.3.1.4. Mechanical Department

The core of the maintenance management team is the mechanical team. Maintenance strategies are developed for the cold box by the Mechanical Department in Sasol and thereafter integrated in the GOs where the repairs are executed. The pre-planning and execution of the GO is the responsibility of the Mechanical Area Manager and it is extremely important to ensure that all departments' scope of work is enclosed in the GO program before the execution can commence. The questionnaire is an excellent tool to support the improvement process of maintenance strategies, if it is answered properly. This will improve the reliability on all critical equipment on the cold box.

3.3.1.5. Inspection Department

The Inspection Department in Sasol is responsible to enforce legal compliance on statutory equipment governed by the Department of Labour. Inspectors issue recommendations on how to repair equipment and the maintenance team performs all the repairs as per recommendation to comply with legal specifications. The Inspection Department renders a service to the maintenance management team and contributes to the long term reliability improvement of statutory equipment.

3.3.1.6. Electrical Department

The Oxygen Department in Sasol is the highest consumer of electricity in the whole factory. The electrical department is responsible in regulating electricity usage and to finding ways of improving electricity usage to support Eskom in the recent electricity problems across South Africa. Equipment must be positively isolated when any repairs commence on the equipment. The two methods of positive isolation are to remove the energy source (electricity) or to isolate the process flow on the equipment. The Electrical Department's input in the questionnaire is crucial in terms of the consistency of the electrical supply. The cold must be operated within agreed parameters.

3.3.2. Questionnaire Distribution, Collection and Analysis Procedures

Inspecting and exploring the primary data, the research process explores the boundaries and shortcomings of the existing process that is utilized by Sasol to maintain the cold box. The primary data supported the discovering of shortcomings in areas of measurement and which areas require improvement to enhance the reliability statistics of the cold box. Pinpointing these measurement areas will provide an improved perception of reliability engineering and the management of the cold box, which leads to better understanding of the difficulties.

3.3.2.1. Population and sample size

The research was conducted on a population of 30 stakeholders in the maintenance management environment. Questionnaires were handed to four participants per discipline, except for Metallurgy and Inspection as they are smaller disciplines and only deliver a service to the maintenance departments. The reason for distributing four questionnaires is to determine an accurate average amongst each discipline. The sample size is kept to 22 as the outcome is sufficient for the research being conducted. Including more in the survey can cause an inaccurate end result due to unwillingness to participate. The aim is to identify four willing participants per discipline, and where possible, acquire their input in the research being conducted.

3.3.2.2. Questionnaire distribution and collection

The questionnaire consists of 28 questions and is six pages long. The questionnaire is available in APPENDIX A. Questionnaires were sent to participants by email and hard copies of the questionnaire were delivered personally to participants without email access. Stakeholders were given one week to review the questions and another week to complete the questionnaire. To follow up on the progress of the participants, an email was sent after one week and another email in the second week to confirm if the participant had completed the questionnaire. If the participants were not done with the questionnaire, an additional week was granted to complete the questionnaire.

3.3.2.3. Data analysis

Data analysis is an extremely important phase in the research process in terms of the desired outcome needed to add value to a field of study. If the data collected in the research is insufficient and not relevant to the study field, it is fair to say that the desired outcome will not be adequate and the research will not add any value to the specific field. The quality of a system output is dependent on the quality of the system input which is where the ‘garbage in – garbage out' principle is derived from (Butler et al., 2010). For the selected study, a descriptive data analysis is applied due to a small sample size. On completion of the data collection, the data is thoroughly validated to verify that the information is relevant to the research topic. A preliminary analysis is conducted on the data that is collected to predict what the possible outcomes will be. Each maintenance management division's data is tabulated based on the response of the individuals and analyzed thoroughly to extract the conclusions of the collected data (Maxwell, 2002).

3.4. SUMMARY

Chapter 3 focused on different methods of accurately finding a solution to the research question and finding an alternative solutions to the problem at hand. The qualitative descriptive research tool that was selected is a questionnaire, to improve the research problem identified in the Sasol cold box. Questionnaires in the Sasol environment are a powerful tool due to the multi-disciplinary environment which the maintenance management is performed in. The qualitative data gathered by the selected methods is a reflection of the maintenance team's experiences and must be implemented in Sasol to improve the approach of maintenance management for more reliable production operations. The academic basis of the literature implemented in the methodology is a major improvement in the maintenance management field. This will lead to more reliable equipment in Sasol and can be implemented by other petrochemical industries which have a cold box in service. Each of the questions in the survey is further scrutinized to highlight the desired outcome and their objectives from the questionnaire.

In Chapter 4, the results of the findings in Chapter 3 are scrutinized and formed into soutions that adress the research question. The data analysis is true reflection of the diverse teams' knowledge on the cold box.

CHAPTER 4

DATA ANALYSIS AND RESULTS

4.1. INTRODUCTION

In any survey, it is crucial for the response rate to be as high as possible to ensure that response unfairness is eliminated. Research found that questionnaire surveys sent by email in only one round have a response rate of between 37% and 45% (Tayie, 2005) (Dillman, 2011). If the questionnaire is distributed via email to individual respondents, the response rate increases to as high as 84% (Dillman, 2011). A total of 30 questionnaires are distributed in the Sasol oxygen environment amongst all relevant disciplines that have extensive experience of the cold box, and especially of the cryogenic process that is implemented in the Sasol operations. The aim of the questionnaire is to determine the qualitative information regarding the improvement of the maintenance strategy to be implemented on the cold box for a more stable and reliable cold box. Trustworthiness and reliability of data collection are imbedded into the questionnaire to collect useful data in terms of the research being conducted. The questionnaire was distributed in only one round, as it was sufficient to qualitatively determine how to improve the current maintenance strategy, and if it was feasible to implement a new maintenance strategy on the cold box. Chapter 4 is a thorough discussion of the results that was collected from the questionnaires.

4.2. CROSS RELATION BETWEEN QUESTIONS

The questionnaire consists of 28 questions, which were formulated to determine certain data relating to the research question. The questions were divided into six categories as was extracted from the relevant sections in the literature. But the questions do not follow chronologically in the analysis. The categories are:

7. Different air separation processes (represented by pink)
8. Maintenance management (represented by green)
9. Maintenance planning (represented by purple)
10. Maintenance strategy (represented by grey)

11. Reliability management (represented by green)

12. Quality management and the RCM process (represented by blue)

Question Number	Questions supporting the argument	Questions based on the following Literature
11	Are there any air separation process challenges that might prevent Sasol to achieve the required oxygen output on the cold box? Explain your answer	2.3. Challenges in the different air separation processes
1	Do you have difficulty coordinating maintenance inspections and repairs with production?	2.4. Maintenance management
14	What does the term maintenance management mean to you?	2.4. Maintenance management
23	How do you estimate the execution time for repair processes on the cold box in Sasol?	2.4. Maintenance management
24	Is it possible to challenge standard repair durations on equipment installed on the cold box and who should challenge the durations not to affect the quality of the repairs being conducted?	2.4. Maintenance management
27	Do you think that it is possible to improve on the current maintenance management system and how would you suggest it can be improved?	2.4. Maintenance management
21	Do you store history information on all critical equipment on the cold box? Explain the method of storage and what data are collected.	2.4.1. Maintenance Plan
9	Do you keep maintenance performance record for the cold box in the oxygen department?	2.4.1. Maintenance Plan.
10	Do you have a productivity report that compares actual performance to planned performances?	2.4.1. Maintenance Plan.
4	Do you use computer support for maintenance planning and tracking?	2.4.1. Maintenance Plan.
8	Do you use priority coding when planning and executing maintenance on the cold box?	2.4.1. Maintenance Plan.
6	Do you depend on maintenance superintendents for all maintenance work supervision for effective execution of maintenance activities?	2.4.1. Maintenance Plan.

7	Do you depend on planners for all maintenance work planning and coordination?	2.4.1. Maintenance Plan.
15	Do you apply condition monitoring techniques on the cold box to predict failures before it occur and what are these techniques?	2.4.2.2.Proactive maintenance
25	Do you identify and procure maintenance materials before actual repair work should commence and how are critical spares identified?	2.4.2.4.Risk based maintenance
12	Do you practice reactive, proactive or design out maintenance on the critical components of the cold box?	2.4.2.Maintenance strategies and techniques
13	What alternative maintenance strategy can be implemented to improve the reliability and stability of the cold box?	2.4.2.Maintenance strategies and techniques
26	Do you think the reliability engineering method that is currently implemented on the cold box is sustainable for long term production output in Sasol? Explain your answer	2.5.1. Why is reliability important?
2	Will online non-destructive examination (NDE) testing contribute to the reliability of the cold box?	2.6.1. Reliability management
3	Do you think Risk Based Inspections on critical equipment on the cold box can contribute to the improvement of the reliability of the cold box?	2.6.1. Reliability management
16	Will additional online monitoring systems improve the current reliability status on the cold box and what systems will you recommend? (For Example Additional Pressure indicators, Temperature indicators, Flow meters etc…)	2.6.1. Reliability management
17	Will active monitoring of the cold box by the production department add value to defect identification and what intervals do you suggest for this inspections?	2.6.1. Reliability management
18	What is your opinion on thermal scanning of the cold box and all critical components as a method to determine online defect on the cold box?	2.6.1. Reliability management
28	Is it feasible to invest in the improvement of reliability of the cold box? Explain	2.6.1. Reliability management
5	Do you have a detailed maintenance inspection check lists that specifies what to inspect on the cold box?	2.6.2.Quality management

20	Do you analyze causes of cold box failures to prevent the same breakdown from happening in future and what do you do with the information afterwards?	2.6.3. Difference between quality- and reliability management
19	Have you identified all critical components on the cold box and what method did you follow to determine the criticality of the specific component of the cold box?	2.7. Reliability-centered maintenance
22	Do you have a specific maintenance budgets for the cold box and can the costing history be tracked per critical component? Explain	2.7.4. RCM utilized as a tool to improve maintenance activities

4.3. DETERMINING THE TRUSWOTHINESS OF THE DATA

It is important to understand the difference between the trustworthiness and reliability of gathered information when collecting data to proof a research question. Trustworthiness, or in other terms validity of data, is when measured data represents what it is set out to represent and meaningful interpretations can be drawn from the data (Sim & Wright, 2000). The most important factor that was considered in compiling the distribution list for the questionnaire was the participants experience level with the cold box and in the oxygen environment. The experience level of all participants was carefully thought through to ensure that all participants could be considered knowledgeable in maintenance management and reliability engineering, or at least the most important aspects thereof. According to the 30 original respondents, the average years of experience of the participants with reliability engineering is fourteen years, with a maximum of 35 and a minimum of three years. Most of the respondents are highly qualified and skilled individuals with extensive knowledge in the petrochemical environment. The respondents were mostly Area Managers, Foremen, Technicians, and Engineers. On Artisan level, the response was noticeably low, which is an indication that these individuals are not office-bound, but hands-on and technical individuals. Figure 11 below indicates the experience level of the participants that took part in the survey.

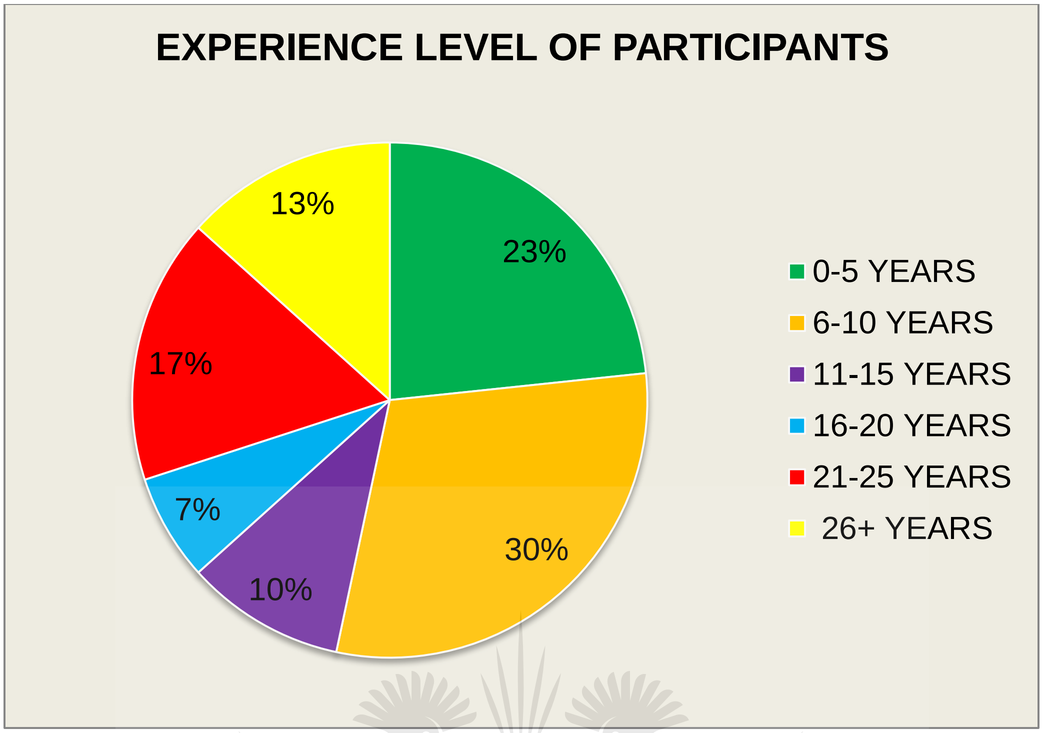


Figure 11 : Experience level of participants

The experience level of the respondents is divided into six (6) different age groups and a distinct colour is allocated to each age group. The group represented by the green segment of the pie chart, is the age group zero to five years' experience. It is evident from Figure 11 that only 23% of the respondents have five years or less experience in the Sasol maintenance management environment. These participants have limited experience in reliability engineering, although the contribution of these individuals is crucial to represent the younger generation's ideas. Of the remaining participants, 67% have more than six years' experience in the maintenance and reliability engineering environment, where valuable experience is gained. The quality of the data that is extracted from the participants is insightful and of high standard. The quality of the answers from the respondents correlated with the literature and was utilized to improve the existing shortcomings of the cold box and to develop the reliability and stability of the cold box.

4.4. ANALYSING QUESTIONNAIRE RESULTS

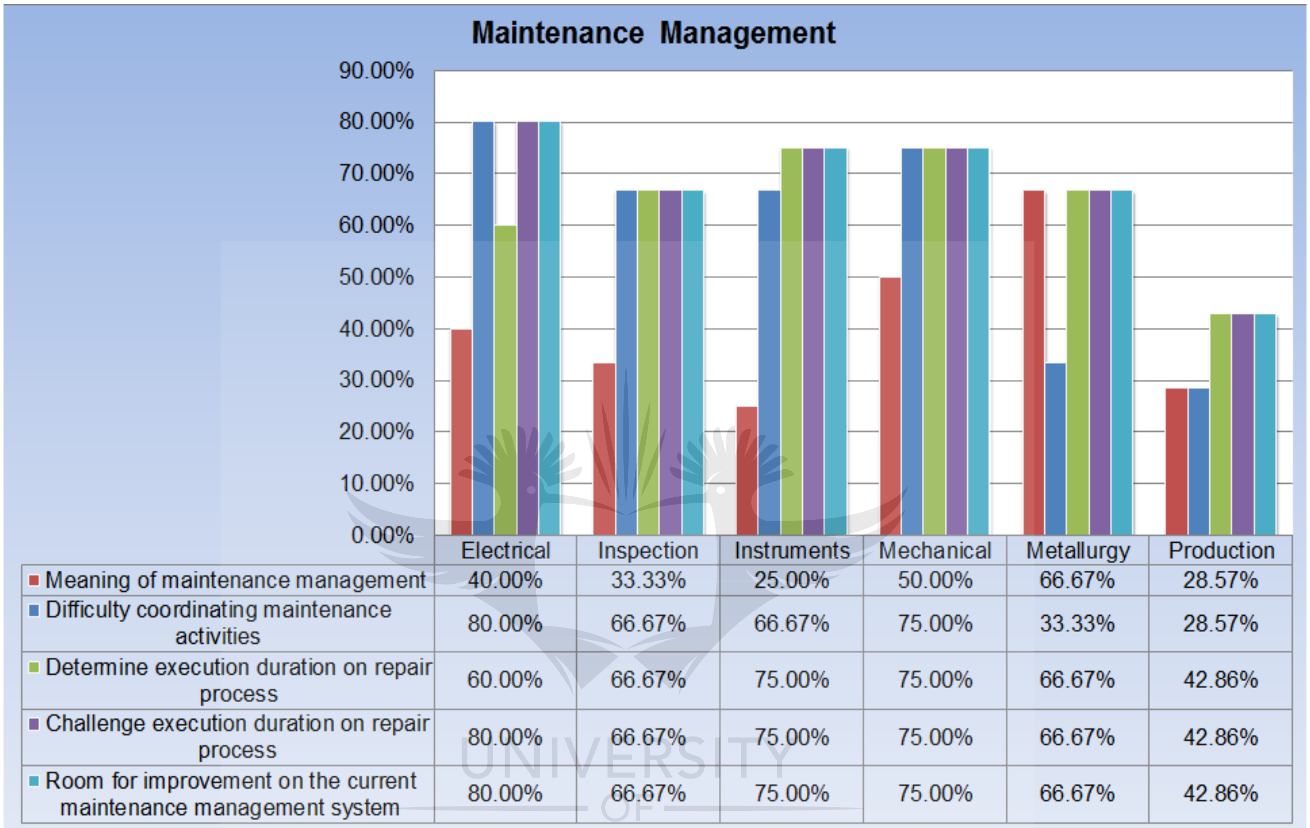
4.4.1. Challenges in the different air separation processes

In the literature, the challenges of the three different identified air separation processes are discussed and the limitations are highlighted. In this section, the goal is to identify any hidden process limitations that are known to the respondents that can influence the production output of the cold box in the oxygen environment. The reliability and stability of the process can be improved with the input of the different disciplines and will contribute to the research questions' answer.

The challenges in the air separation process in Sasol influence the production output of the cold box and require attention to ensure the equipment performs as per specification. The quality of the data collected is of high standard and multiple corrective actions have been derived from the findings. The maintenance team identified that the equipment is extremely old and this causes a continuous challenge to achieve oxygen and nitrogen purity levels, which directly affect the performance of the cold box. During summer, the ambient temperature has an enormous impact on the performance of the cold box due to the atmospheric pressure that is lower and the amount of pressure that must be utilized is higher. According to the participants, the cryogenic air separation process is the only process that is suitable for the Sasol production requirements as the volume and purity of the oxygen that must be delivered is very high. If the information gathered is taken into consideration in the maintenance strategy compilation, it will improve the reliability of the cold box. The results and findings from the questionnaires can be viewed in Appendix B.

4.4.2. Maintenance management

The literature discusses maintenance management in detail and how a lack maintenance management can have a negative impact on the reliability of the cold box. In this section, the emphasis is to determine the knowledge of the respondents on the maintenance management system being utilized by Sasol and what can be done to improve the process. The core focus of this study is to determine if an alternative maintenance strategy can be implemented on the cold box to improve the reliability and stability of the cold box. Improving the maintenance management system that is implemented on the cold box will ensure that maintenance is conducted more systematically and in an organised fashion. The aim is for the maintenance team to work in a well-structured and organized environment to have time available to concentrate on improving the reliability and stability of the cold box. In Figure 12 below, the results for the maintenance management section is displayed graphically.



	Electrical	Inspection	Instruments	Mechanical	Metallurgy	Production
Meaning of maintenance management	40.00%	33.33%	25.00%	50.00%	66.67%	28.57%
Difficulty coordinating maintenance activities	80.00%	66.67%	66.67%	75.00%	33.33%	28.57%
Determine execution duration on repair process	60.00%	66.67%	75.00%	75.00%	66.67%	42.86%
Challenge execution duration on repair process	80.00%	66.67%	75.00%	75.00%	66.67%	42.86%
Room for improvement on the current maintenance management system	80.00%	66.67%	75.00%	75.00%	66.67%	42.86%

Figure 12 : Maintenance management

In Figure 12 the horizontal plane on the graph represents the specific department that is questioned on the maintenance management topic. The percentages represent the respondents that answered yes to the question asked. As shown in the graph, each question is allocated a specific colour which enhances the visibility on the graph. The question being asked can be located in APPENDIX A and the exact breakdown on how the departments responded to the questions can be viewed in APPENDIX B in the relevant section. The vertical plane of the graph indicates the percentages of the respondents per department. Each response per department is marked on the vertical plane, with the unique color allocated to the different questions. It is noticeable in Figure 12 that there is a slight difference between the answers of the Electrical, Inspection, Instruments, Mechanical departments and the Metallurgical and Production departments. The reason for the slight difference is that Electrical, Instruments, and Mechanical departments are the core of the maintenance team and these departments work according to the Work Management system. Inspection and Metallurgy deliver a service to the maintenance management team and are highly skilled technical individuals. Inspections' response is close to the maintenance team's results due to the department's involvement in the day to day inspections on the cold box. Production has slightly different opinions on the questions being asked about maintenance management as the department is not performing any technical duties in the work management process.

The results and quality of the answers in the completed questionnaires confirm that the maintenance team is knowledgeable and skilled individuals with maintenance background from multiple disciplines. The concern identified in the results is that the multidisciplinary team does not have a common understanding when it comes to maintenance and the management thereof. It is difficult to improve the maintenance strategy that is currently utilized on the cold box to support the research question, if the level of understanding on maintenance management is not noticeably understood by the entire team. A mutual understanding on maintenance management is essential in the team for all individuals to work towards an improved philosophy for the cold box.

The high percentage of respondents that indicated the lack of alignment between the maintenance departments and the production department is a major concern, which has a direct influence on the reliability of the cold box. The cold box must be inspected frequently and must be aligned with the maintenance strategy that is implemented on the equipment. If the maintenance philosophies are not adhered to, the risk of unforeseen breakdowns and regular breakdowns is going to increase drastically.

The respondents indicated that the durations for all repairs being conducted on the cold box are treated with high intensity. The findings are that the scope of work is determined by experienced maintenance personnel. These are mostly foremen from different disciplines, captured in a formal program which is drafted by the planning department. The participants indicated that previous experience in cold box repairs is utilized in determining the repair duration. The duration of the repair process affects the availability of the cold box, which has a negative impact on the production output of the cold box.

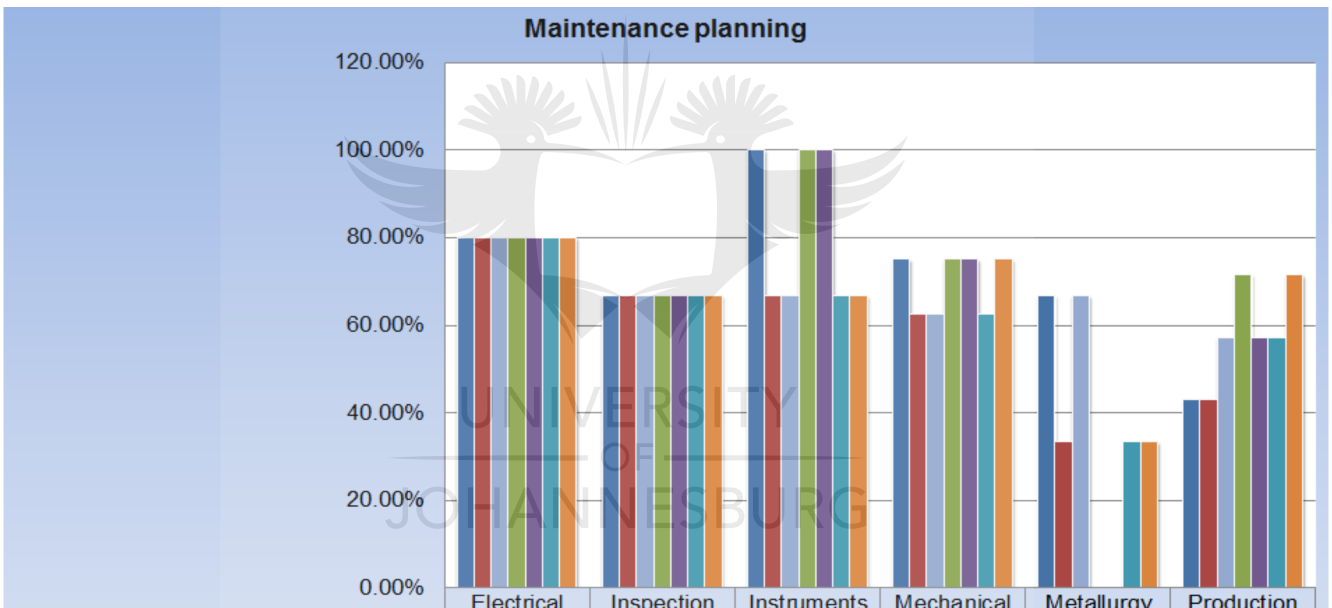
The majority of the respondents added that repair times are always challenged and it is the responsibility of the relevant area manager to challenge the duration, with the input of the maintenance foreman, who has an extensive amount of experience in the repair processes. The respondents stipulated that planning and scheduling of maintenance activities permanently have the quality and duration of the repair work in mind. Production targets drive the priority, but quality control and quality assurance processes ensure that quality of repairs are not compromised.

The current maintenance and restoration program that is in place has already yielded better maintenance of the equipment and the auxiliaries around it, by a thorough overhaul of all accessible components and inspection. More inspection information that become available over time improves the next iteration of the Risk Based Inspection (RBI) analysis done on the equipment. After a particular GO on a cold box, a multi-discipline meeting should be organized where the prevailing issues should be evaluated and methods to prevent against the shortcomings must be documented for future GOs. This will improve the reliability of the cold box over time. The last insight from the respondents to improve the maintenance management system is to build other oxygen machines and stop pushing the current machines hard for better stability.

In this section, all questions being asked are interrelated. The meaning of maintenance management is investigated to evaluate if the Sasol personnel and the maintenance team understand the concept. The follow up questions rely on comprehensive understanding of the maintenance management system to highlight the significance of the coordination of the repairs that must be conducted on the cold box. The coordination is related to the repair duration of the cold box which is essential to improve the downtime of the cold box and ensure that the equipment is more stable and reliable. Lastly, the maintenance management process is always worth investigating, to improve the performance of the cold box for a reliable and stable oxygen production environment. The in depth breakdown of all separate questions can be viewed in APPENDIX B.

4.4.3. Maintenance planning

In the literature, an overview of the data that is essential to collect for future reference, in terms of reliability improvement on the cold box, was discussed in depth. The literature emphasized the importance of collecting data and creating a history on all critical components on the cold box. In this section, the concentration is to determine the knowledge of the respondents on maintenance planning and record keeping in the Sasol oxygen environment. The research argument is that Sasol is currently doing maintenance on a cold box with a black box approach, which makes it difficult for the maintenance team to predict when a failure might occur. The aim is to move away from a black box approach to a proactive orientated maintenance approach, which originates at the planning and execution of maintenance activities on the cold box. Improving the maintenance planning system that is implemented on the cold box will ensure that maintenance is conducted with a formalized program and history can be built up on different equipment. The reliability of the cold box can be improved drastically if the equipment has sufficient breakdown history and a performance record.



	Electrical	Inspection	Instruments	Mechanical	Metallurgy	Production
History tracking on critical components	80.00%	66.67%	100.00%	75.00%	66.67%	42.86%
Maintenance performance records	80.00%	66.67%	66.67%	62.50%	33.33%	42.86%
Productivity report	80.00%	66.67%	66.67%	62.50%	66.67%	57.14%
Utilizing CMMS	80.00%	66.67%	100.00%	75.00%	0.00%	71.43%
Utilizing priority coding	80.00%	66.67%	100.00%	75.00%	0.00%	57.14%
Dependence of maintenance work supervision	80.00%	66.67%	66.67%	62.50%	33.33%	57.14%
Dependence on planners	80.00%	66.67%	66.67%	75.00%	33.33%	71.43%

Figure 13 : Maintenance planning

In Figure 13, the horizontal plane on the graph represents the specific department that were questioned on the maintenance planning topic. The percentages represent the respondents that answered yes to the question asked. As shown in the graph, each question is allocated a specific colour which enhances the visibility on the graph. The question being asked can be located in APPENDIX A and the exact breakdown on how the departments responded to the questions can be viewed in APPENDIX B in the relevant section. The vertical plane of the graph indicates the percentages of the respondents per department. Each response per department is marked on the vertical plane, with the unique colour allocated to the different questions. It is noticeable in Figure 13 that there is a slight difference between the answers of the Electrical, Inspection, Instruments, Mechanical departments and the Metallurgical and Production departments. The reason for the slight difference is that Electrical, Instruments, Mechanical departments are the core of the maintenance team and these departments work according to the Work Management system. Inspection and Metallurgy deliver a service to the maintenance management team and are highly skilled technical individuals. Inspections' response is close to the maintenance team's results due to the department's involvement in the day to day inspections on the cold box. Production has slightly different opinions on the questions being asked about maintenance management as the department is not performing any technical duties in the work management process.

The respondents indicated that process information is captured via the control system for a period of time, and can be interrogated for historic trends. Maintenance information is kept in a CMMS Systems, Applications, Products (SAP) that includes failure, cost, planning, and scheduling information. SAP is a interactive computerized system that enhance internal and cross functional planning, When the Inspection Department does inspections on the cold box, reports are kept in an electronic system called Plant Condition Management Software (PCMS) and statutory inspection reports in a central filling room. PCMS is a system where the degradation of all statutory equipment can be managed and viewed. The method of storage in the filing room is hard copy files of the equipment on the cold box.

A high percentage of the respondents indicated that performance records are stored and available in the oxygen environment. The records help to detect negative or positive trends on the equipment and the information is used in the maintenance strategy review sessions, to improve the existing maintenance strategies that are implemented on the cold box. The equipment's reliability and stability will gradually improve to ensure that the cold box is more predictable.

The best way to improve the current maintenance performance on GOs, is to reduce the downtime of the cold box. This can be achieved by comparing the planned performance to the actual performance of the GO. A high percentage of respondents indicated that planned performance and actual performance are analyzed in their respective departments. The analysis will direct the maintenance team to the time consuming activities that are performed on the repair process and the attention of the team will move to this activity. The reduction in downtime will lead to improved availability of the cold box and more stable equipment.

A high percentage of the respondents indicated that Sasol use a CMMS to safely store maintenance information. This information consists of failure, cost, planning, and scheduling information. To review history information on defective components, the focus moves to the failure mechanism on the critical components of the cold box. If the failure mechanisms are removed or minimized on the cold box, the reliability of the equipment will improve drastically in time.

The high percentage of respondents that make use of priority coding when conducting maintenance repairs is an indication that breakdowns can be analyzed and improved via the maintenance strategy that is implemented on the cold box. An analysis on the priority coding being used for the maintenance repairs, directs technical personnel to the components on the cold box which need attention. If the priority one (breakdown) coding that is used is very high, it means the cold box unforeseen breakdowns are very high. Unforeseen breakdowns cause major production losses which influence the production schedule negatively. The focus on the maintenance priority coding directly supports the research question as it helps to improve the reliability of the cold box if it is analyzed correctly.

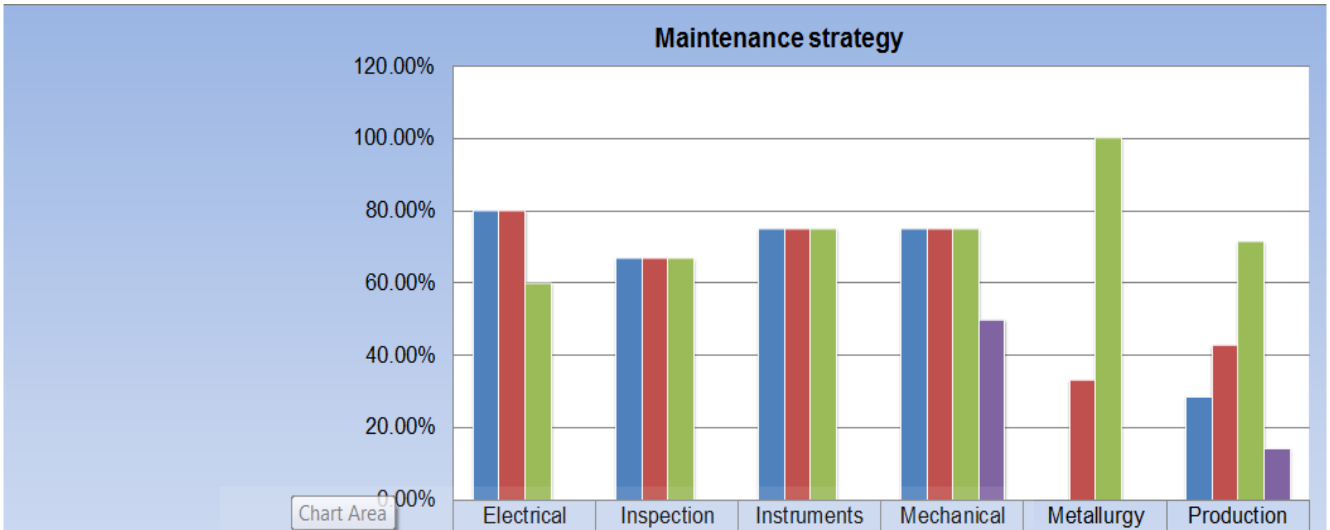
A high percentage of respondents indicated that they rely on supervision is an indication that quality management is important to Sasol. To verify that maintenance activities are executed correctly, as per specification on the cold cox, it is important to include activities in the execution program for supervision to quality check technical work. The reliability of the cold box will improve drastically if the maintenance activities that must be performed on the cold, are done correctly and with high quality components. The downtime of the cold box is also influenced if the maintenance team needs to conduct rework due to a lack of effective quality control.

The majority of the respondents depend on external planners to plan and coordinate the maintenance activities during GOs. The planning department are specialists in planning and coordination of maintenance repairs, with complex execution plans. The service being delivered by the planning department enables the maintenance team to focus on improving the existing maintenance activities and the reliability of the equipment.

In this section all questions being asked are interrelated. The section starts of by evaluating if sufficient history is gathered on the cold box's critical components. The follow up questions are related to the history, but require the respondents to identify if performance records are kept for future reference in Sasol. The planning of the repairs on the cold box is a complex and very important part of the planning process in Sasol, which must be established and the nature of planning must be determined through the priority coding to improve the reliability of the cold box. The effectiveness of the execution phase of the maintenance repairs is extremely important and the input of the maintenance team is required to determine if sufficient supervision is allowed to ensure the correctness. Lastly, the validity of the maintenance repair planning is tested to ensure the planning is conducted by specialists in the planning environment. The in depth breakdown of all separate questions can be viewed in APENDIX B.

4.4.4. Maintenance strategies

The literature discussed the different types of maintenance strategies and how they affect the cold box in Sasol. It emphasized proactive maintenance and the importance thereof for reliability and stability of the cold box. Risk based maintenance is investigated in the literature and how to identify critical spares for pro-activeness to shorten the amount of downtime of the cold box. The research argument is that Sasol is currently doing maintenance on the cold box with a black box approach which makes it difficult for the maintenance team to predict when a failure might occur. The core focus of this study is to determine if an alternative maintenance strategy can be implemented on the cold box, to improve the reliability and stability of the cold box. The aim of this section is to identify what maintenance strategy is currently utilized on the cold box. If the current maintenance strategy is known, it must be scrutinized and the shortcomings must be identified. This section assists to identify the best possible maintenance strategy for the cold box to improve the reliability and stability of the cold box. Improving the maintenance strategy will decrease the amount of unforeseen breakdowns in the oxygen environment on the cold box.



	Electrical	Inspection	Instruments	Mechanical	Metallurgy	Production
What maintenance strategy are implemented on the cold box (reactive)	80.00%	66.67%	75.00%	75.00%	0.00%	28.57%
What alternative maintenance strategy can be implemented (proactive)	80.00%	66.67%	75.00%	75.00%	33.33%	42.86%
Condition monitoring techniques	60.00%	66.67%	75.00%	75.00%	100.00%	71.43%
Identify material before breakdown	0.00%	0.00%	0.00%	50.00%	0.00%	14.29%

Figure 14 : Maintenance strategy

In Figure 14, the horizontal plane on the graph represents the specific department that is questioned on the maintenance strategy topic. The percentages represent the respondents that answered reactive maintenance to the first question, proactive maintenance to the second question and yes to the rest of the questions asked. As illustrated in the graph, each question is allocated a specific colour which enhances the visibility on the graph. The question being asked can be located in APPENDIX A and the exact breakdown on how the departments responded to the questions can be viewed in APPENDIX B in the relevant section. The vertical plane of the graph indicates the percentages of the respondents per department. Each response per department is marked on the vertical plane, with the unique colour allocated to the different questions. It is noticeable in Figure 14 that there is a slight difference between the answers of the Electrical, Inspection, Instruments, Mechanical departments and the Metallurgical and Production departments. The reason for the slight difference is that Electrical, Instruments, Mechanical departments are the core of the maintenance team and these departments work according to the Work Management system. Inspection and Metallurgy deliver a service to the maintenance management team and are highly skilled technical individuals. Inspections' response is close to the maintenance team's results due to the department's involvement in the day to day inspections on the cold box. Production has slightly different opinions on the questions being asked on maintenance management as the department is not performing any technical duties in the work management process. The cross functional knowledge equality is because these individuals all participate in the maintenance strategy review sessions which are held twice yearly for improvement of existing maintenance strategies in the oxygen environment. The maintenance team utilizes the skills of the individuals to improve maintenance strategies for enhanced results in the maintenance environment. All maintenance personnel have extensive knowledge in the reliability engineering field and the high quality answer confirms the statement.

A high percentage of the respondents indicated that the current maintenance strategy that is implemented on the cold box is reactive maintenance. Most of the respondents stated that it is very difficult to perform proactive maintenance. The cold box and all its critical components are within a structure that contains insulation material called perlite. The alternative maintenance strategy that a high percentage of the respondents suggested is a proactive maintenance strategy although it is challenging to implement. Due to the construction of the cold box accessibility is very limited, but the material of construction is very well suited for the operation of the equipment. This alternative maintenance strategy will improve the reliability and stability of the cold box and all critical components.

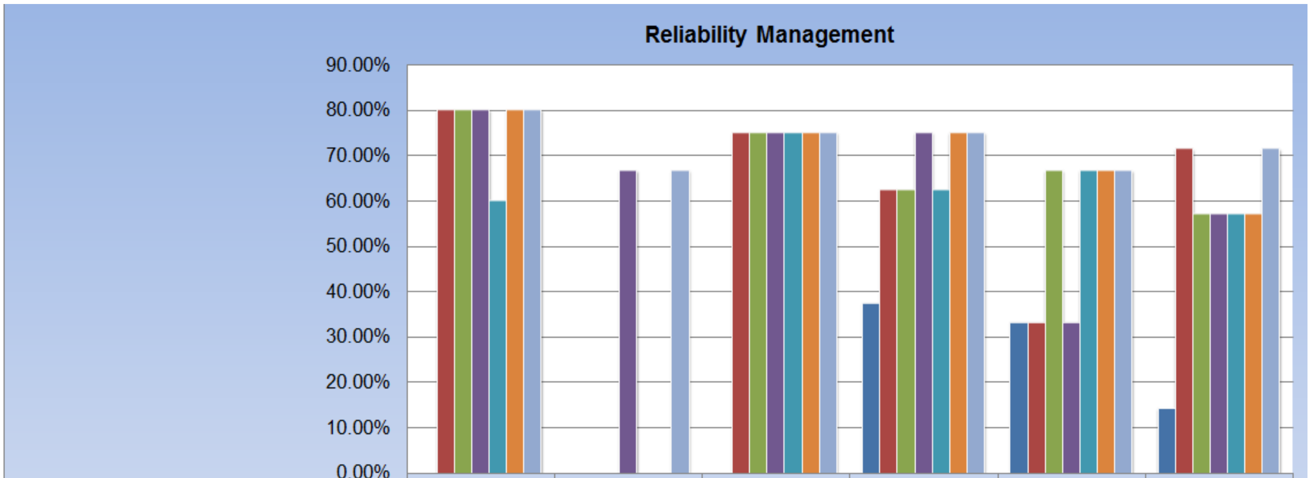
A high percentage of the respondents indicated that the cold box has active condition monitoring equipment installed. They indicated that not nearly enough is done to detect failures before they occur. The common condition monitoring equipment that is currently installed are pressure indicators, temperature indicators, analyzers flow meters, and rota-meters. Improving the reliability and stability of the cold box, the mutual suggestion from the maintenance team is that additional research on new technology monitoring equipment must be done for better results.

A high percentage of the respondents indicated that no spares are identified and ordered prior to the repair process. Most of the spares can only be scoped when access to the equipment is gained which is limited. Critical spares with high costs, long lead times, and high production impacts are justified and kept on site, but for the cold box there are limited identified spares. The maintenance team believes that savings would be made should the spares be identified before the GO start.

In this section all questions being asked are interrelated. The first step in this section is to determine the existing maintenance strategy that is utilized on the cold box. In the follow up questions, the alternative maintenance strategy to be implemented on the cold box are extracted from the respondents. The pro-activeness of respondents is tested by identifying if condition monitoring on the cold box is in place and ways to improve on the existing measures that are in place in Sasol. The last measure to determine pro-activeness amongst the respondents is to identify if the different role players consider and think about what spares are needed for the maintenance process in advance. The questions being asked in this section are based on improving the maintenance strategy and complete the loop in conducting successful maintenance on the cold box. The in depth breakdown of all separate questions can be viewed in APENDIX B.

4.4.5. Reliability management

The literature discussed reliability management in detail and the importance thereof in terms of the reliability and stability of the cold box. According to the literature, the monitoring of reliability management on the cold box is a proactive measure that can be put in place to prevent unforeseen breakdowns on the cold box. The maintenance team has extensive knowledge in the maintenance environment. The literature further emphasizes the importance of the cold box to perform to its intended function. The research argument is that Sasol is currently doing maintenance on the cold box with a black box approach which makes it difficult for the maintenance team to predict when a failure might occur. This study is to determine if an alternative maintenance strategy can be implemented on the cold box to improve the reliability and stability of the cold box. In this section, the emphasis is put on proving how important reliability of the cold box is and what additional methods can be explored to enhance the reliability and stability of the cold box. This section will explore to what extent managers in Sasol will financially support reliability improvement. The improvement in reliability will ensure a highly predictable cold box and more stable operations.



	Electrical	Inspection	Instruments	Mechanical	Metallurgy	Production
Is the reliability method sustainable in Sasol	0.00%	0.00%	0.00%	37.50%	33.33%	14.29%
NDE's contribute to reliability	80.00%	0.00%	75.00%	62.50%	33.33%	71.43%
Additional online monitoring contribute to reliability	80.00%	0.00%	75.00%	62.50%	66.67%	57.14%
Active monitoring contribute to reliability	80.00%	66.67%	75.00%	75.00%	33.33%	57.14%
Thermal scanning contribute to reliability	60.00%	0.00%	75.00%	62.50%	66.67%	57.14%
RBI contribute to the reliability	80.00%	0.00%	75.00%	75.00%	66.67%	57.14%
Feasibility to invest in reliability	80.00%	66.67%	75.00%	75.00%	66.67%	71.43%

Figure 15 : Reliability management

In Figure 15 the horizontal plane on the graph represents the specific department that is questioned on the reliability management topic. The percentages represent the respondents that answered yes to the question asked. As shown in the graph, each question is allocated a specific colour which enhances the visibility on the graph. The question being asked can be located in APPENDIX A and the exact breakdown on how the departments responded to the questions can be viewed in APPENDIX B in the relevant section. The vertical plane of the graph indicates the percentages of the respondents per department. Each response per department is marked on the vertical plane, with the unique colour allocated to the different questions. It is noticeable in Figure 15 that there is a slight difference between the answers of the Electrical, Instruments, Mechanical and Production departments and the Metallurgical and Inspection departments. The reason for the slight difference is that Electrical, Instruments, Mechanical departments are the core of the maintenance team and these departments work according to the Work Management system. Inspection and Metallurgy deliver a service to the maintenance management team and are highly skilled technical individuals. Production has slightly different opinions on the questions being asked on maintenance management as the department is not performing any technical duties in the work management process.

The majority of the respondents indicated that there is room for improvement on the current reliability engineering method which is currently implemented on the cold box. Multiple respondents indicated that the current method is unsustainable, because of the limited available information on the cold box and because the knowledge on all critical components amongst the maintenance team is limited. The maintenance team indicated that the functioning of all critical components is not common knowledge to all personnel conducting maintenance on the cold box. The cold box was designed in France and most of the information is extremely difficult to obtain.

A high percentage of the respondents indicated that online NDEs on the critical components of the cold box contribute to the improvement of the reliability of the equipment. If the deterioration of the critical components can be tracked and noted it will help to plan the decommissioning of the cold box and prevent unforeseen breakdowns. This will improve the stability of the cold box and ensure that the planned production output is met at all times.

A high percentage of respondents indicated that additional online monitoring techniques will contribute to the reliability improvement on the cold box. The respondents indicated that the materials inside the cold boxes are selected to handle the low temperatures they are subjected to, however, temperature and pressure excursions may cause stress gradients which may result in failures. In addition, high pressures may change the properties of these materials. Temperature and pressure gauges may assist in monitoring these variables. Smart instrumentation is being utilized (like transmitters,valve positioners, and control systems), but the monitoring, feedback, and recording part, used for prediction, is way underutilized. The chances of improving the reliability and stability of the cold box are much better when the visibility of the process and materials is observable.

The majority of the respondents stated that the production department already has plant inspections that must be conducted on equipment in the oxygen plant, but limited on the cold box. The respondents suggested that daily inspections should be performed on the critical components of the cold box to detect leaks, temperature, and pressure fluctuations. If leaks and other defects are detected before it causes unforeseen breakdowns, the inspections are effective and serve their cause. A concerning discovery is that respondents rather will go for technology and not rely on humans for inspections as humans are less reliable than technology. If the inspections perform their intended function, the reliability of the equipment improves with time.

The majority of the respondents stated that thermal scanning is highly effective in detecting leaks on the cold box, if the perlite surrounding the vessel does not interfere with the method. Thermal scanning is extremely expensive; expenditures should weigh up to the benefit the system will gain from the process. If thermal scanning is used, however, it should be complemented by conventional methods such as gauges, since thermal scanning is affected by many variables (for example, emissivity of surface of the material). If leaks can be detected online, the reliability of the cold box will improve drastically and the breakdowns can be controlled to a certain extent.

The respondents supported the idea of risk based inspection maintenance on the cold box. Stoppages of equipment have always affected the production capability of physical assets by dropping production, increasing running costs, and interfering with customer services. The RBI process will ensure the cold box has less serious breakdowns, which can cause major production losses. The RBI process will improve the reliability and stability of the cold box and will save Sasol a lot of effort and money.

The cost of reliability system improvement must be weighed up to the cost of the current maintenance activities recorded in time, as well as the cost of down time of the cold box. Usually, the cost of down time outweighs the cost of normal reactive maintenance if it is done correctly. The high percentage respondents that agreed on the feasibility of investing in improving the current reliability of the cold box, indicate that there is room for improvement on the reliability method followed on the equipment. Due to the criticality of the equipment in the air separation process and the Sasol oxygen environment, it is vital to maintain the equipment correctly and seek methods of prolonging the valuable life of the equipment. Although the equipment is old, the challenge is to extend the lifespan of the cold box to the point where it is still economically viable to operate the equipment in its physical state. The reliability of the cold box is such a key factor that it is worth investing in the process improvement.

In this section all questions being asked are interrelated and create valuable insight in the reliability management of the cold box. The section starts off by testing the sustainability of the existing reliability method implemented on the cold box. The four questions following test the possibility of online techniques to improve the reliability and stability of the cold box. The section is closed off by testing the possibility if management will find it feasible to invest in reliability management. The questions are extremely well thought through and the response from the participants is insightful and will positively contribute to the improvement of reliability and stability on the cold box. The in depth breakdown of all separate questions can be viewed in APENDIX B.

4.4.6. Quality management and the RCM process

The literature discussed reliability-centered maintenance in detail and how the cold box benefits from this process. One of the steps in the RCM process is to do a risk analysis on all components to determine the criticality of the component and the impact this component has on the cold box in terms of the reliability of the equipment. If the critical components are identified and maintained on the correct maintenance strategy, the reliability on the cold box will improve drastically. The literature discusses the importance of quality management in Sasol and the impact of high quality products and services to positively influence the company. Failure analysis and the long term influence it has on the cold box are discussed. If the equipment tends to experience a high volume of unforeseen breakdowns, the quality of the equipment is not suitable for the environment where it is installed. The literature put emphasis on the importance of knowing exactly how funds are allocated on maintenance activities that are conducted on the cold box, to determine the cost effectiveness of all critical components on the equipment. Utilizing the RCM process and implementing proper quality management, the research argument is answered. The argument is that Sasol is currently doing maintenance on the cold box with a black box approach which makes it difficult for the maintenance team to predict when a failure might occur. The core focus of this study is to determine if an alternative maintenance strategy can be implemented on the cold box to improve the reliability and stability of the cold box. The quality and reliability of the maintenance that is conducted on any equipment is vital to enhance the performance of the cold box. The aim in this section is to identify if the maintenance team conduct quality repair processes and if reliability centered maintenance is utilized on the cold box.

	Electrical	Inspection	Instruments	Mechanical	Metallurgy	Production
Is all critical components identified on the cold box	80.00%	66.67%	75.00%	62.50%	0.00%	71.43%
Do you have a detailed inspection checklist	0.00%	0.00%	50.00%	37.50%	0.00%	42.86%
Do you analyze causes of failures on the cold box	80.00%	66.67%	66.67%	75.00%	66.67%	71.43%
Do you have a specific budget for the cold box	80.00%	66.67%	75.00%	75.00%	33.33%	42.86%

Figure 16 : Quality management - RCM process cross interpretation

In Figure 16 the horizontal plane on the graph represents the specific department that is questioned on quality management and the RCM process. The percentages represent the respondents that answered yes to the question asked. As shown in the graph, each question is allocated a specific colour which enhances the visibility on the graph. The question being asked can be located in APPENDIX A and the exact breakdown on how the departments responded to the questions can be viewed in APPENDIX B in the relevant section. The vertical plane of the graph indicates the percentages of the respondents per department. Each response per department is marked on the vertical plane, with the unique colour allocated to the different questions. It is noticeable in Figure 16 that there is a difference between the answers of the Electrical, Instruments, Mechanical and Production departments and the Metallurgical and Inspection departments. The reason for the slight difference is that Electrical, Instruments, Mechanical departments are the core of the maintenance team and these departments work according to the Work Management system. Inspection and Metallurgy deliver a service to the maintenance management team and are highly skilled technical individuals. These departments are not hands-on involved in the maintenance processes that are conducted on the cold box, but if breakdowns occur the input of these departments is crucial to find the root cause of the breakdown. Production has slightly different opinions on the questions being asked on maintenance management as the department does not perform any technical duties in the work management process.

The majority of the respondents indicated that the critical components on the cold box are identified. According to the respondents the FMECA process is utilized to identify all critical components on the cold box. The concern is that multiple respondents indicated that the process of critical component identification must be repeated, since the equipment is fairly unknown to all disciplines. If all critical components on the cold box are identified, the emphasis on maintenance will shift to critical equipment and the reliability and stability of the cold box will improve.

The indication is that the absence of inspection checklists is a major concern for the quality of inspections conducted on the cold box. If there is no guidance of what to inspect on the cold box, there is no guarantee of successful inspections. An inspection that is noted is the key to success in improving the reliability of the cold box and less unforeseen breakdowns will occur on the equipment.

A high percentage of the maintenance team indicated that failure investigations are performed. Failure of equipment goes through a rigorous root cause failure analysis (RCFA) process. After the failure investigation is done, a report outlining the cause of failure and recommendations thereof are handed to the Mechanical Maintenance department. Proper fault finding and analysis of breakdowns is crucial in determining the correct root cause of the failing component on the cold box and engineering it out becomes easier. If the root cause of the breakdown is known, the maintenance approach is slightly different and the quality of the equipment and the reliability of the equipment improve.

The response indicates that the cold box has a distinct budget. All maintenance activities, planned or breakdowns are captured with a CMMS and the costs can be tracked. The costing of the maintenance activities is linked a work breakdown structure (WBS) which has a specific cost code linked to it. The equipment with abnormally high expenditure can be investigated and re-evaluated to be more cost effective or replaced with an alternative solution. The quality of the equipment improves as well as the reliability of the cold box.

In this section all questions being asked are interrelated. The critical components are the fundamental focus of the entire reliability process to improve the reliability of the cold box. The follow up questions identify the quality of maintenance management being conducted on the critical components. Improving the entire quality management process is of utmost importance to identify where the root cause of the failures are, to tulitmately improve the process. If the maintenance budget is categorized and is divided into different critical categories, the attention can be shifted to the problem areas on the cold box. The in depth breakdown of all separate questions can be viewed in APENDIX B.

4.5. DETERMINING THE RELIABILITY OF THE COLLECTED DATA

The reliability of the qualitative research method is important in terms of the effectiveness of the data collected in the data collection process. Reliability of a research instrument relates to the accuracy of the data collected in the research process. For example if a question is asked to the same respondent more than once the answer to the question should be the same (Anderson et al., 2008). The reliability of a research instrument concerns the level to which the instrument yields the same outcomes on recurrent trials or amongst different departments with the same backgrounds. The identified participants that contributed to this research being conducted on the cold box are all technical experts in some or other way. Sasol apply the same maintenance management process throughout the entire company, which is called the work management process. The test for reliability specifically tests the consistency of the participants' answers. The method to test the reliability of the questionnaire is as follow: Three (3) different samples are identified, which is independently selected to demonstrate the reliability of the research method. The reliability of the collected data can be declared reliable, if the participants from the six (6) different departments' answers correspond and a pattern of consistency is identified. The reliability test is conducted on questions seven (7), twenty one (21) and twenty seven (27), which is randomly selected to determine the reliability of the research tool utilized for the research (Salkind, 2009).

The sample size consists of twenty two (22) respondents and this is two thirds of each department that participated in the survey. The reason for the two thirds is that the smallest department only consists of three employees and only two responded to the questionnaire. One third is not enough for consistent data; all departments answered more than two thirds which provide consistent feedback. All departments must be granted an equal opportunity to influence the research outcome.

Variability of collected data				
ID	**Question 7**	**Question 21**	**Question 27**	**Designation**
1	1	1	1	Electrical
2	1	1	1	Electrical
3	1	1	1	Electrical
4	1	1	1	Electrical
5	1	1	1	Inspection
6	1	1	1	Inspection
7	1	1	1	Instruments
8	1	1	1	Instruments
9	2	1	1	Instruments
10	1	1	1	Mechanical
11	1	1	1	Mechanical
12	1	1	1	Mechanical
13	1	1	1	Mechanical
14	1	1	1	Mechanical
15	1	1	1	Mechanical
16	1	1	1	Metallurgy
17	3	1	1	Metallurgy
18	1	2	2	Production
19	1	1	1	Production
20	1	1	1	Production
21	1	2	1	Production
22	1	1	3	Production
	$\sum$	$\sum$	$\sum$	
X	25	24	25	
N	22	22	22	
M	1.1364	1.091	1.1364	
s	1.135	1.09	1.135	

Table 2 : Variability of collected data (Leedy & Ormrod, 2010)

The mean is the sum of a set of scores divided by the number of scores (Salkind, 2009). The mean for each of the three selected questions is worked out in Excel and is illustrated in the Table 2.

$$M = \sum X/N \qquad (1)$$

M = mean of all the scores.

$\sum$ = the summation of the set of scores.

N = the size of the sample for which the mean is calculated.

"The standard deviation is the average amount that each of the individual scores varies from the mean of the set of scores" (Salkind, 2009). Calculating the standard deviation, the mean is incorporated into the formula below. The standard deviation for each of the three selected questions is worked out in Excel and is illustrated in the Table 2.

$$s = \frac{\sqrt{\Sigma\,(X-M)^2}}{N} \qquad (2)$$

s = standard deviation

$\sum$ = the summation of the set of scores

X = an individual score

M = mean of all the scores

N = number of observations

A standard deviation of five that is calculated for each question means that from the 22 respondents only five respondents deviated from the mean. The average standard deviation for the three selected questions is 5.09% which in other words mean that 94.91% participants responded consistently to the three questions. The variability test confirms the reliability of the research tool.

4.6. DATA QUALITY VERIFICATION

Qualitative research does not rely on numerical data due to its emphases on explaining events and people. Qualitative research also emphasizes issues related to events and people. It is utilized to improve and understand the emphasized reasons for their decisions on changing the maintenance strategy of the cold box (Fox & Bayat, 2007). Qualitative research utilized explanatory methods to understand, or interpret phenomena in terms of the meaning that people add to the study. The aim is to extract meaningful and exhaustive information from the respondents which have extensive experience and knowledge in the unfamiliar field of the cold box (Biggam, 2011). The strategies that are utilized in this research document to validate the data are the following:

4.6.1. Feedback from others

The researcher collected all the completed questionnaires and analyzed the findings in depth. The questionnaire, a summary of the findings and recommendations is compiled for review purposes. The researcher arranged a brain storming session with a group of reliability engineers which is experts in reliability engineering to verify if the gathered information is valid and applicable to the cold box and the field of studies (Leedy & Ormrod, 2010).The group consist of five reliability engineers with extensive Sasol experiense especially on the cold box. The individuals are all involved in reliability engineering practices that are utilized in Sasol and they are knowlegable with the existing process that are utilized on the cold box. The chosen group members all went for intenal and external reliability engineering training which make the source reliable to verify if the gathered data is of high standard.

4.6.2. Respondent validation

The researcher collected all the completed questionnaires and analyzed the findings in depth. The data that is collected is processed and valuable conclusions are extracted from the findings. A recommendation is then derived from the conclusions after it has gone through a thorough analysis. The conclusions and recommendations are discussed with the 22 respondents who completed the questionnaire in the specified time. The following question is asked to verify if the answers are interpreted correctly.

- Do you agree with the conclusions and recommendations?
- Do the conclusions make sense based on the experience you have on the cold box?
- Do you feel that anything is excluded from the conclusions?
- Is the information that is presented applicable to the answers in your questionnaire? (Leedy & Ormrod, 2010)

4.6.3. Peer debriefing

The last data quality verification that is conducted is the peer debriefing. The researcher asked assistance from several collegues and the study leader of the researcher obtaining information which might have been neglected unintentionally. The researcher discussed what is expected from the research being conducted with knowledgeable individuals with firsthand experience in theoretical writing of research documents and implemented the findings into the mini dissertation. Various meetings are conducted to ensure that the individuals also keep track of the progress of the wright up process.

4.7. SUMMARY

Chapter 4 discussed the qualitative outcomes that resulted from the questionnaire which were distributed amongst the maintenance team in the Sasol oxygen environment. The purpose of the questionnaire is to support the research argument. The argument is that the current maintenance on the cold box is conducted on a black box approach which makes it difficult to predict when failures might occur. This questionnaire determines if an alternative maintenance strategy can be implemented on the cold box and the outcome presents possible solutions to perceived problems. Due to excellent participation of 73.33% of the respondents, the direction is established for an effective conclusion and recommendations to follow in chapter five.

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. INTRODUCTION

The aim of this study is to improve the existing maintenance strategy that is currently implemented on the cold box in Sasol to a more stable and reliable production output of the equipment, due to the criticality of the equipment in the petrochemical process. The literature discussed and highlighted the challenges that can be expected in the oxygen environment and on the cold box. A qualitative analysis is done to determine the weaknesses and limitations in the maintenance environment, which might affect the reliability of the cold box. In this section, the findings of the qualitative analysis are discussed and recommendations are made to improve the maintenance strategy and maintenance management system for improvement of the reliability of the cold box.

5.2. CONCLUSION

The study into the reliability engineering, stability, and the improvement of the existing maintenance strategy on the cold box is the foundation of the research. The conclusions that can be derived from the qualitative analysis are:

- The cold box is extremely old and this causes a continuous challenge to achieve oxygen and nitrogen purity levels which directly affect the performance of the cold box.
- The multidisciplinary team does not have the same understanding when it comes to maintenance and the management of the cold box.
- The majority of the different departments that participated in the study make use of external planners to plan and coordinate maintenance activities during maintenance repairs on the cold box.
- It is evident that reactive maintenance that is currently conducted on the cold box is a concern to the improvement of reliability on the cold box.

- Additional online monitoring equipment can positively contribute to reliability management and the visibility of unforeseen breakdowns.
- The quality of maintenance activities is extremely important to improve the reliability of the cold box.

5.3. RECOMMENDATION

The recommendation that is derived from the research is based on the data that is collected from the qualitative research tool combined with the literature. The argument is that Sasol is currently doing maintenance on the cold box with a black box approach which makes it difficult for the maintenance team to predict when a failure might occur. The emphasis of this study is to determine if an alternative maintenance strategy can be implemented on the cold box to improve the reliability and stability of the cold box. The recommendations are made to support the research argument and to add value to the existing maintenance process that is followed in Sasol. The process of improving the reliability engineering management on the cod box will flow more orderly and flawlessly if it is broken down into stages. The three stages are short term, medium term and long terms goals. The following recommendations are derived from the research process

Short term goals

- Training in maintenance management departments is essential to allign the mutual thinking of the entire maintenance team.
- All departments must be alligned with the maintenance strategy’s requirements that are implemented on the cold box. The cold box must be decommissioned when specified by the technical expert team, to ensure no deviation from the agreed operating conditions.
- Maintenance activities must be supervised and reviewed by experienced personnel to guarantee effective execution of maintenance activities.
- Inspection and repair checklists must be revised and implemented to improve the quality of the inspections and maintenance that is conducted on the cold box.

Medium term goals

- Sasol has a unique and successful method of collecting history on the critical components of the cold box. The only way to ensure that this method stay effective is to always have the latest version CMMS to store history for future reference.
- Reactive maintenance strategies on any equipment are ineffective and the suggestion is to implement proactive maintenance to prevent unforeseen breakdowns on the cold box.

Long term goals

- It is worth investing time and resources in developing a business case for the replacement of the cold box in Sasol. The age of equipment negatively affects the quality and effectivity of the production output.
- It is worth investing in new and improved reliability engineering methods to extend the cold box's lifespan.
- New technology online monitoring equipment on the cold box will improve the visibility of the critical components and prevent unforeseen breakdowns, it is recommended to invest in new technology.
- Critical spares with high costs, long lead times and high production impacts must be justified and kept on site to limit downtime of the cold box.

If the recommendations are adhered to and implemented in the Sasol oxygen environment, it will improve the reliability and stability of the cold box. It will create a sustainable reliability process and improve the lifespan of the equipment. The research indicates that reliability engineering and effective maintenance management on the cold box will improve the production output of the equipment and Sasol will benefit from it.

APPENDIX A - QUESTIONNAIRE

THE FEASIBILITY OF RELIABILITY ENGINEERING AND MANAGEMENT IN THE PETROCHEMICAL ENVIRONMENT: THE AIR SEPARATION UNIT IN SASOL (COLD BOX)

The questionnaire survey is compiled to help the researcher understand the influence of high quality reliability engineering and maintenance management performed on the cold box units in Sasol. The researcher is a student from the University of Johannesburg studying M_{PHIL} Engineering Management at the faculty of Engineering and Built Environment. The qualitative survey being conducted is important to determine the feasibility of reliability engineering and management of maintenance on the cold box and if it will be beneficial to Sasol to improve the existing maintenance strategies implemented on the cold box. The information gathered by the survey will be analyzed and from the analysis recommendations will follow if the survey pinpoints any weaknesses. The questionnaire is distributed in a multidisciplinary environment amongst subject experts with different backgrounds and opinions to obtain a common understanding on the relevant question being asked. The quality of a system output is dependent on the quality of the system input which is where the ‘garbage in – garbage out’ principle is derived from (Butler, Holden, & Lidwell, 2010). It is thus crucial to complete the questionnaire as honestly and accurately as possible in order to determine the best possible result. The answers from the participant are used for academic purposes only and the identity of the participant will be kept confidential and anonymous at all times. The survey takes approximately thirty (30) minutes to complete all twenty eight (28) questions and it is of utmost importance to answer accurately and honestly.

The answers to all the questions are purely based on experience and knowledge in your field of expertise. There is no correct or incorrect answer in the survey therefor it is very important to answer all questions based on your experience and knowledge on the cold box. The survey can be scanned and emailed on completion to Richer Stadler If any of the questions is unclear and need some explanation feel free to contact Richter Stadler.

Contact Number: 076 420 7979 / 017 610 7557, Email address: richter.stadler@sasol.com

Thank you for participating in the survey. Your contribution is much appreciated.

THE FEASIBILITY OF RELIABILITY ENGINEERING AND MANAGEMENT IN THE PETROCHEMICAL ENVIRONMENT: THE AIR SEPARATION UNIT IN SASOL (COLD BOX)

Company name :

Department:

Number of years' experience in Sasol

Please complete the following questionnaire with specific regard to the above enquiry, by placing a CROSS **X** in the appropriate box next to the question.

	Yes	No	Not Applicable
1. Do you have difficulty coordinating maintenance inspections and repairs with production?	☐	☐	☐
2. Will online non-destructive examination (NDE) testing contribute to the reliability of the cold box?	☐	☐	☐
3. Do you think Risk Based Inspections on critical equipment on the cold box can contribute to the improvement of the reliability of the cold box?	☐	☐	☐
4. Do you use computer support for maintenance planning and tracking?	☐	☐	☐
5. Do you have a detailed maintenance inspection check lists that specifies what to inspect on the cold box?	☐	☐	☐

	Yes	No	Not Applicable
6. Do you depend on maintenance superintendents for all maintenance work supervision for effective execution of maintenance activities?	☐	☐	☐
7. Do you depend on planners for all maintenance work planning and coordination?	☐	☐	☐
8. Do you use priority coding when planning and executing maintenance on the cold box?	☐	☐	☐
9. Do you keep maintenance performance record for the cold box in the oxygen department?	☐	☐	☐
10. Do you have a productivity report that compare actual performance to planned performances?	☐	☐	☐

11. Are there any air separation process challenges that might prevent Sasol to achieve the required oxygen output on the cold box? Explain your answer
12. Do you practice reactive, proactive or design out maintenance on the critical components of the cold box?
13. What alternative maintenance strategy can be implemented to improve the reliability and stability of the cold box?
14. What does the term maintenance management mean to you?
15. Do you apply condition monitoring techniques on the cold box to predict failures before it occur and what are these techniques?
16. Will additional online monitoring systems improve the current reliability status on the cold box and what systems will you recommend? (For Example Additional Pressure indicators, Temperature indicators, Flow meters etc…)

17. Will active monitoring of the cold box by the production department add value to defect identification and what intervals do you suggest for this inspections?
18. What is your opinion on thermal scanning of the cold box and all critical components as a method to determine online defects on the cold box?
19. Have you identified all critical components on the cold box and what method did you follow to determine the criticality of the specific component of the cold box?
20. Do you analyze causes of cold box failures to prevent the same breakdown from happening in future and what do you do with the information afterwards?
21. Do you store history information on all critical equipment on the cold box? Explain the method of storage and what data are collected.
22. Do you have a specific maintenance budgets for the cold box and can the costing history be tracked per critical component? Explain

23. How do you estimate the execution time for repair processes on the cold box in Sasol?
24. Is it possible to challenge standard repair durations on equipment installed on the cold box and who should challenge the durations not to affect the quality of the repairs being conducted?
25. Do you identify and procure maintenance materials before actual repair work should commence and how are critical spares identified?
26. Do you think the reliability engineering method that is currently implemented on the cold box is sustainable for long term production output in Sasol? Explain your answer
27. Do you think that it is possible to improve on the current maintenance management system and how would you suggest it can be improved?
28. Is it feasible to invest in the improvement of reliability of the cold box? Explain

Thank you for your corporation and contribution towards this research survey.

APPENDIX B – DATA ANALYSIS

RELIABILITY ENGINEERING AND MANAGEMENT IN THE PETROCHEMICAL ENVIRONMENT: THE AIR SEPARATION UNIT IN SASOL (COLD BOX) QUESTIONNAIRE ANALYSIS

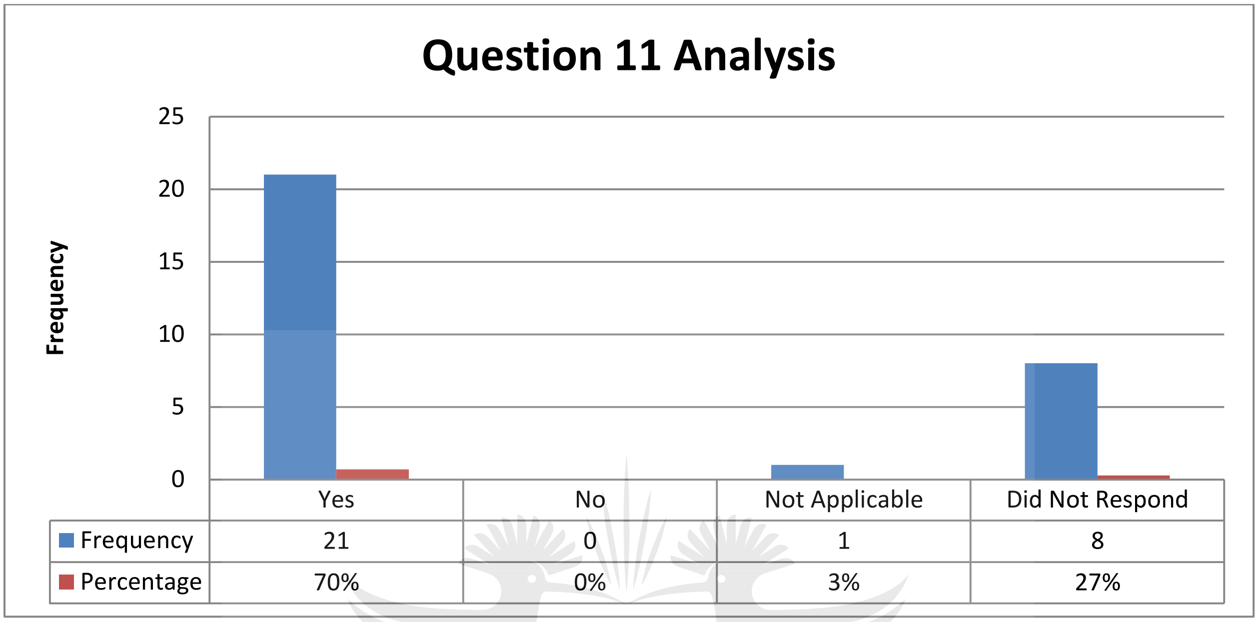
RESPONDENT	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Q 13	Q 14	Designation
1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	Electrical
2	1	1	1	1	2	1	1	1	1	1	1	1	2	1	Electrical
3	1	1	1	1	2	1	1	1	1	1	1	1	2	2	Electrical
4	1	1	1	1	2	1	1	1	1	1	1	1	2	2	Electrical
5	1	3	2	1	2	1	1	1	1	1	1	1	2	2	Inspection
6	1	3	2	1	2	1	1	1	1	1	1	1	2	1	Inspection
7	1	1	1	1	1	1	1	1	1	1	1	1	2	2	Instruments
8	1	1	1	1	2	1	1	1	2	2	1	1	2	2	Instruments
9	2	1	1	1	1	2	2	1	1	1	1	1	2	1	Instruments
10	1	2	1	1	2	2	1	1	2	1	1	1	2	1	Mechanical
11	1	1	1	1	2	1	1	1	1	1	3	1	2	2	Mechanical
12	1	1	1	1	1	1	1	1	1	1	1	1	2	2	Mechanical
13	1	1	1	1	2	1	1	1	1	1	1	1	2	1	Mechanical
14	1	1	1	1	1	1	1	1	1	1	1	1	2	1	Mechanical
15	1	1	1	1	1	1	1	1	1	2	1	1	2	1	Mechanical
16	1	3	1	3	2	1	1	3	3	1	1	2	2	1	Metallurgy
17	2	1	1	3	2	2	3	3	1	1	1	2	3	1	Metallurgy
18	2	1	1	1	1	1	1	1	1	1	1	2	2	2	Production
19	1	1	1	1	1	1	1	1	1	1	1	2	1	2	Production
20	2	1	3	1	2	1	1	1	1	1	1	2	3	1	Production
21	1	1	1	1	1	3	1	3	3	1	1	1	2	2	Production
22	2	1	1	1	3	1	1	1	3	3	1	1	2	1	Production

RELIABILITY ENGINEERING AND MANAGEMENT IN THE PETROCHEMICAL ENVIRONMENT: THE AIR SEPARATION UNIT IN SASOL (COLD BOX) QUESTIONNAIRE ANALYSIS														
RESPONDENT	Q 15	Q 16	Q 17	Q 18	Q 19	Q 20	Q 21	Q 22	Q 23	Q 24	Q 25	Q 26	Q 27	Q 28	Designation
1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	Electrical
2	1	1	1	2	1	1	1	1	1	1	2	2	1	1	Electrical
3	2	1	1	1	1	1	1	1	2	1	2	2	1	1	Electrical
4	1	1	1	1	1	1	1	1	1	1	2	2	1	1	Electrical
5	1	2	1	2	1	1	1	1	1	1	2	2	1	1	Inspection
6	1	2	1	2	1	1	1	1	1	1	2	2	1	1	Inspection
7	1	1	1	1	1	1	1	1	1	1	2	2	1	1	Instruments
8	1	1	1	1	1	2	1	1	1	1	2	2	1	1	Instruments
9	1	1	1	1	1	1	1	1	1	1	2	2	1	1	Instruments
10	1	1	1	1	1	1	1	1	1	1	1	2	1	1	Mechanical
11	1	1	1	1	1	1	1	1	1	1	2	3	1	1	Mechanical
12	1	1	1	1	1	1	1	1	1	1	2	2	1	1	Mechanical
13	1	2	1	2	1	1	1	1	1	1	1	1	1	1	Mechanical
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Mechanical
15	1	1	1	1	2	1	1	1	1	1	1	1	1	1	Mechanical
16	3	1	2	1	2	1	1	2	1	1	2	1	1	1	Metallurgy
17	1	1	1	1	2	1	1	1	1	1	2	2	1	1	Metallurgy
18	1	1	1	3	1	1	2	2	1	2	2	2	2	1	Production
19	1	1	1	1	1	1	1	1	1	1	3	2	1	1	Production
20	1	1	1	1	1	1	1	1	2	1	1	1	1	1	Production
21	1	1	1	1	1	1	2	3	3	3	2	2	1	1	Production
22	1	2	2	1	1	1	1	1	1	1	3	3	3	1	Production

Code	**Response Item**
1	Yes
2	No
3	Not Applicable

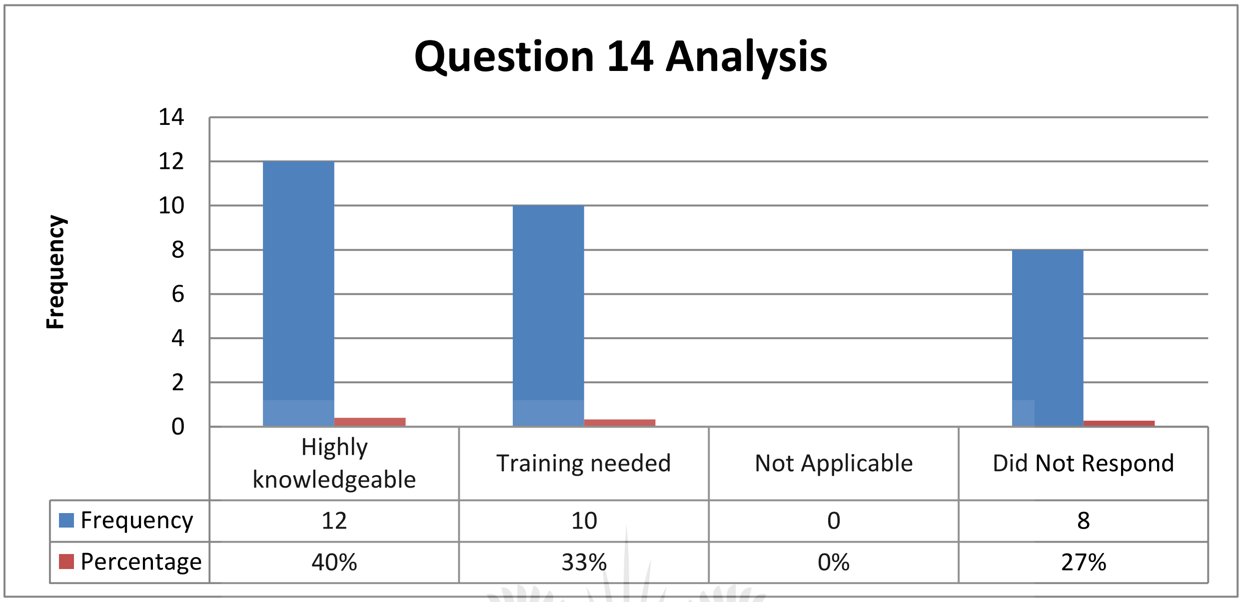
Challenges in the different air separation processes

Below is the data collected from all participants in the multidisciplinary maintenance management environment that are narrowly involved with the cold box.

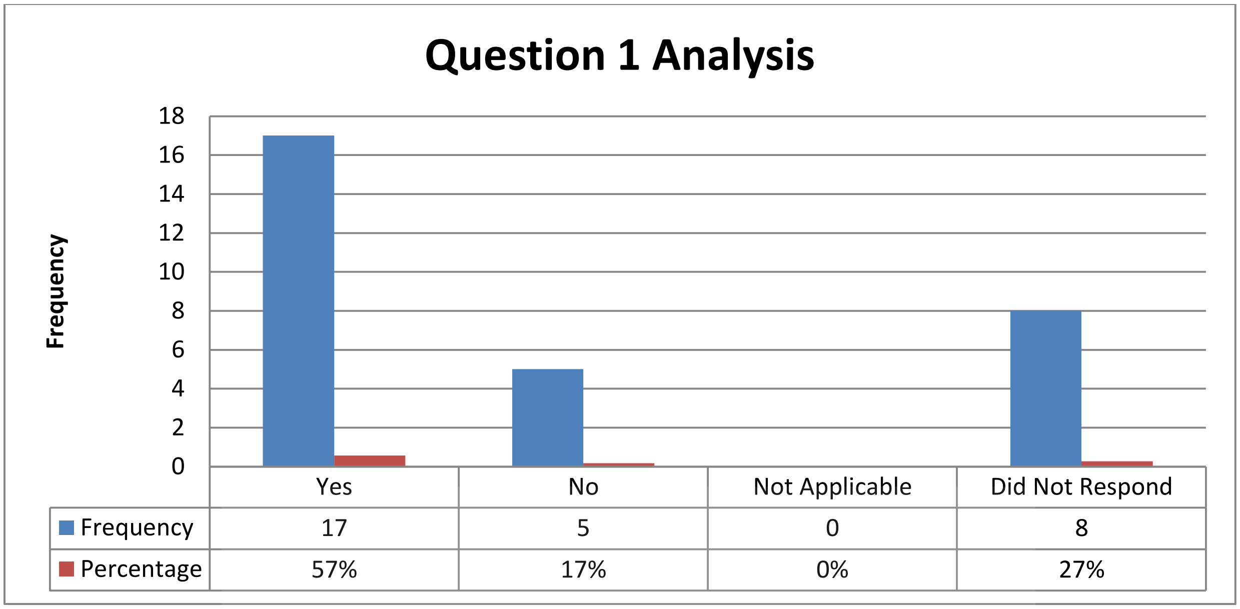


The graph indicate that from the total of thirty (30) participants that took part in the survey, twenty one (21) identified that Sasol are facing challenges that might prevent the oxygen department from achieving the desired production output on the cold box to support the oxygen demand for the factory. One (1) respondents indicated that the question is not applicable to their field of expertise and eight (8) did not respond to the question.

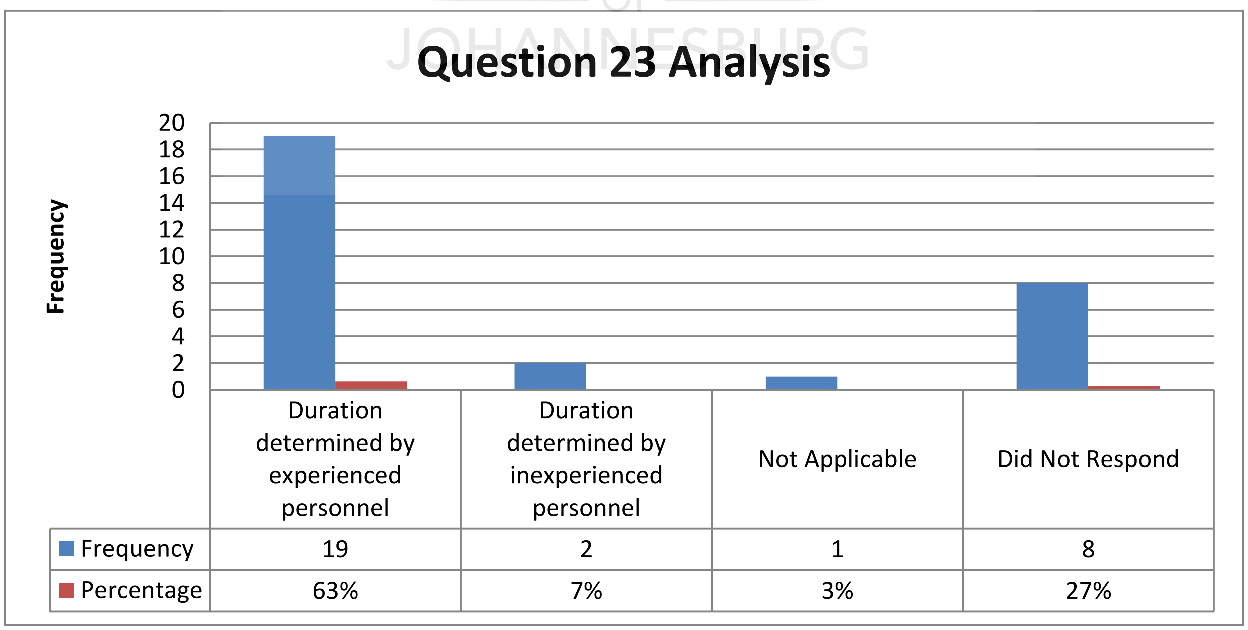
Maintenance management



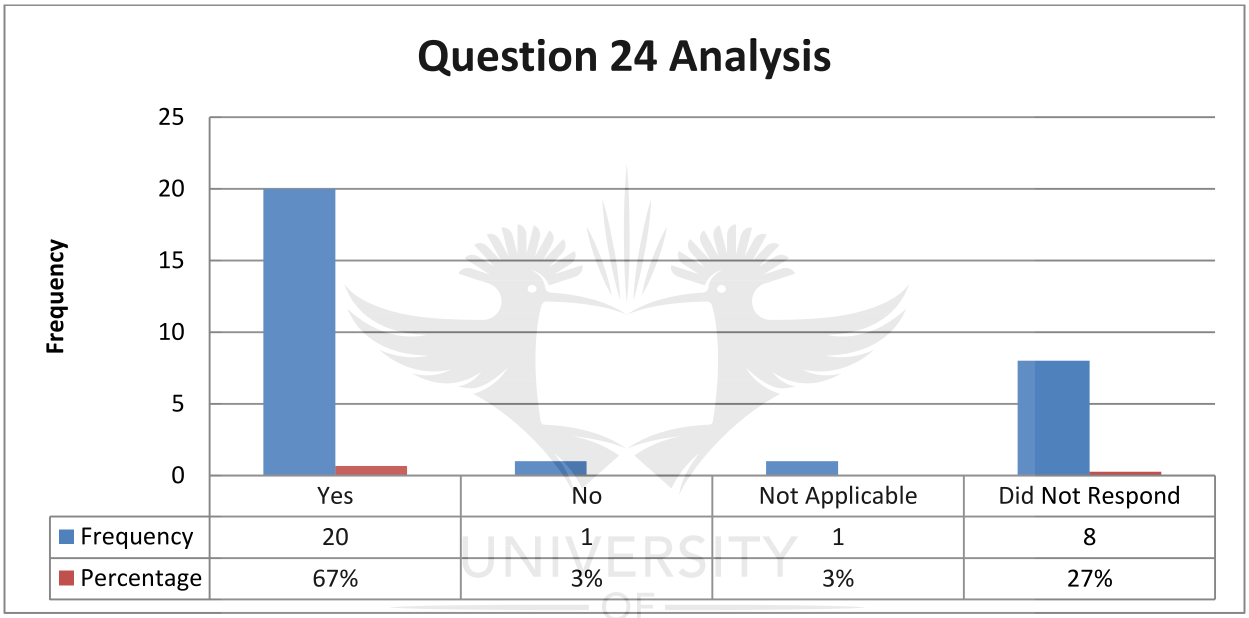
The graph indicates that twelve (12) of the thirty (30) respondents have a clear understanding what the term maintenance management means and ten (10) do not have an idea. It is clear that most of the respondents know what maintenance management means, but the entire maintenance team should be on a high level of understanding to ensure the team performs exceptional on the cold box to maintain and improve the reliability of the equipment. Eight (8) participants did not respond to the question.



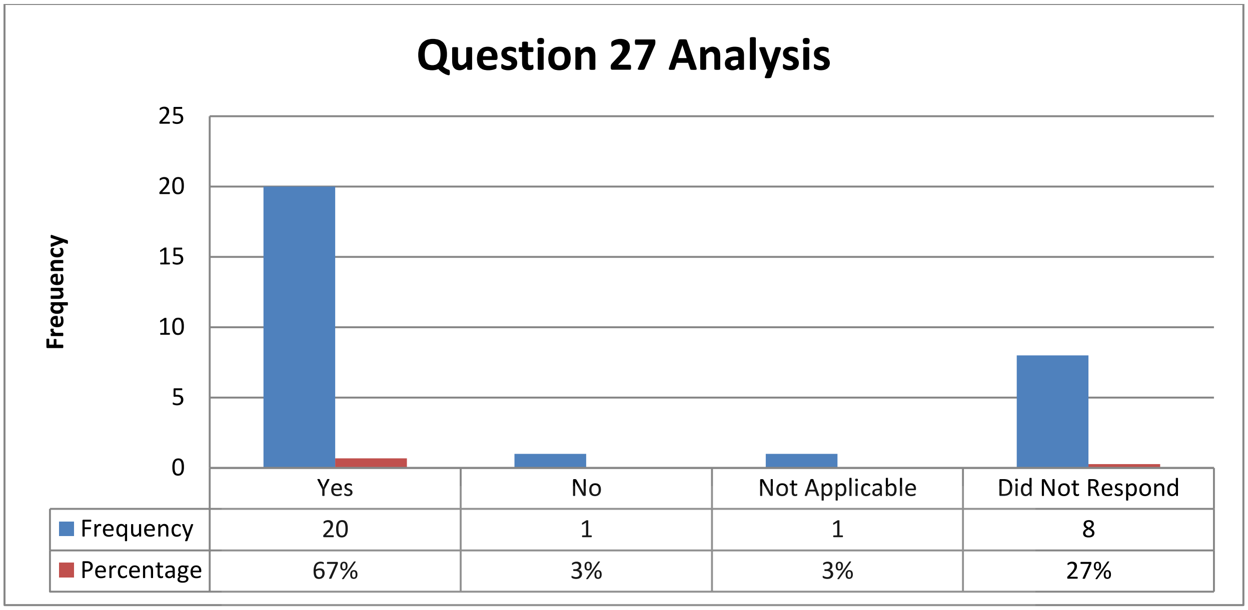
The graph indicates that seventeen (17) of the thirty (30) respondents acknowledged that there is difficulty in Sasol to coordinate inspections and repairs on the cold box with the production department whereas five (5) respondents did not anticipate any problems coordinating inspections or repairs with the production department in Sasol oxygen department. Eight (8) respondents did not respond to the question. This might have serious consequences in terms of unforeseen breakdowns on the cold box as the cold box has to be overhauled and maintained on an agreed schedule to reduce unforeseen breakdowns.



The graph indicates that nineteen (19) of the thirty (30) respondents indicated that the repair durations for critical activities are determined from experienced and knowledgeable maintenance personnel and well established techniques. Two (2) respondents did not agree that the repair durations are determined by experienced personnel and one (1) respondent indicated that the question is not applicable to their department. The last result is that eight (8) respondents did not participate in the questionnaire. The duration of the cold box GO's is extremely long and although the repair durations are determined by experienced personnel, it can still be challenged which is why question twenty four (24) is asked.

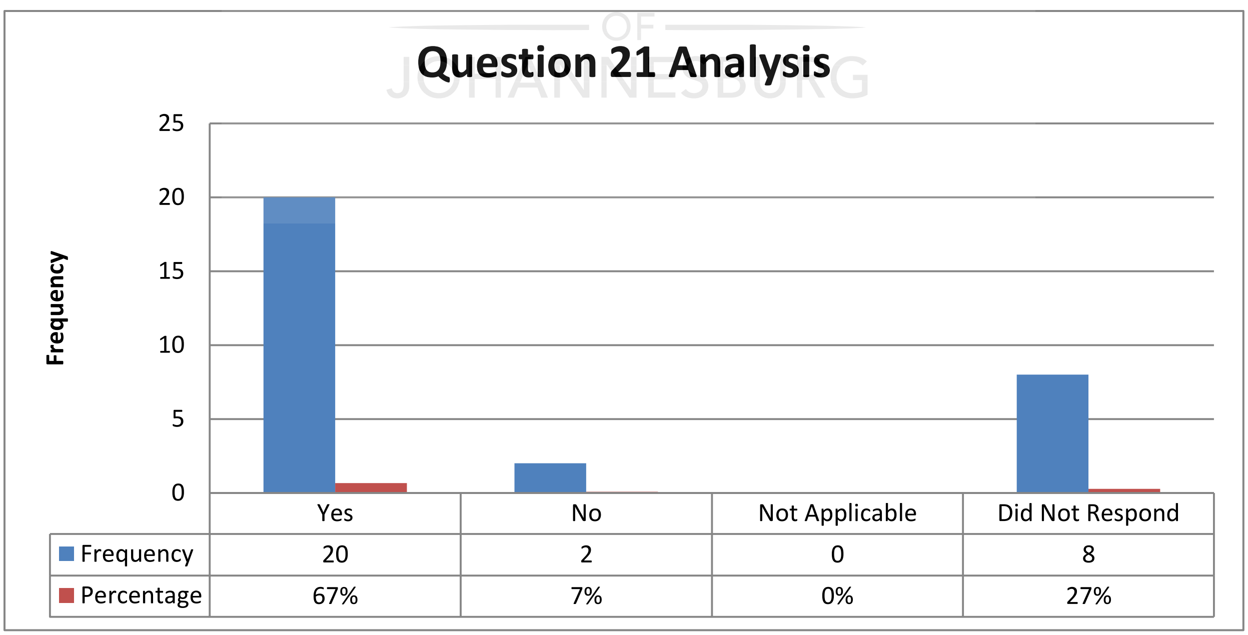


The graph indicates that twenty (20) of the thirty (30) respondents agreed that it is possible to challenge the repair duration on all critical tasks on a cold box GO. One (1) respondent did not agree that it is possible to challenge repair durations of tasks being executed and one (1) respondent indicated that the question is not applicable to his department. Lastly eight (8) respondents did not participate in the survey.

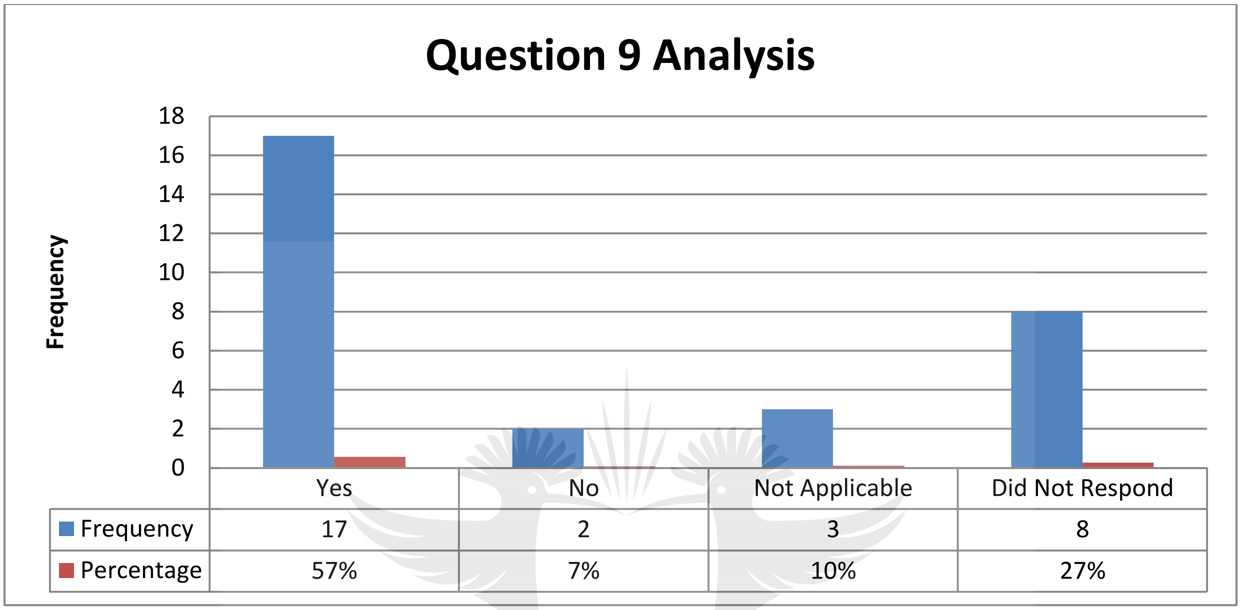


The graph indicates that twenty (20) of the thirty (30) respondents agreed that it is possible to improve the current maintenance management system that is currently implemented on the cold box. One (1) respondent indicated that the current maintenance management system is sufficient; one (1) respondent indicated that the question is not applicable to his department and eight (8) respondents did not respond to the question.

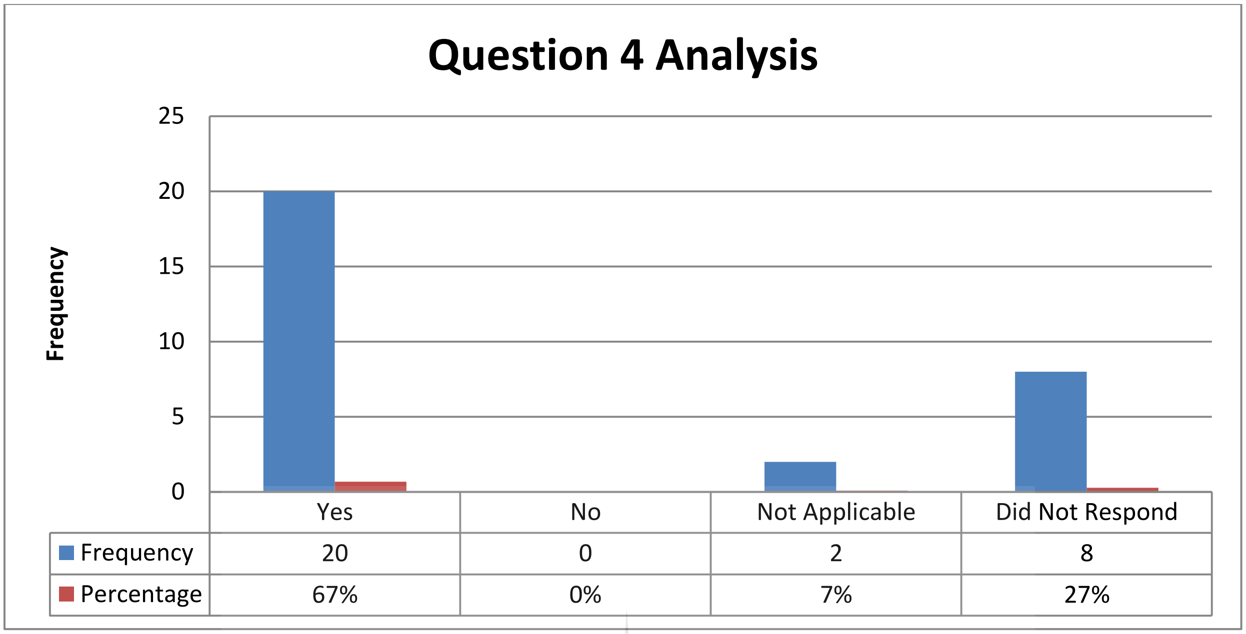
Maintenance planning



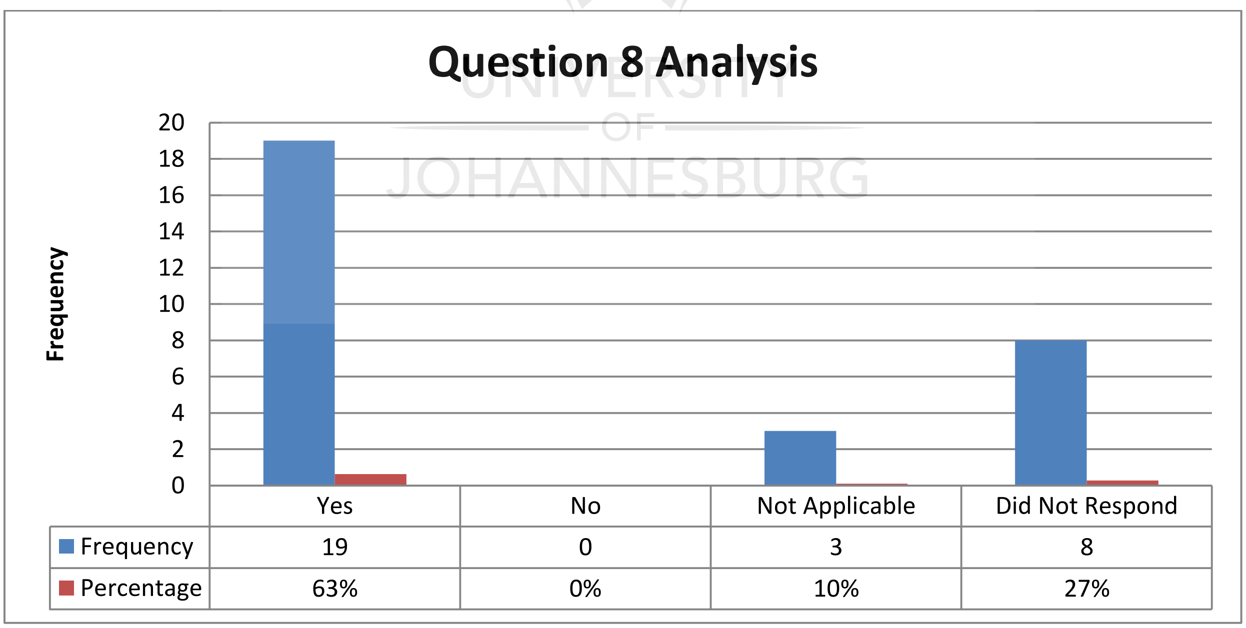
The graph indicates that twenty (20) of the thirty (30) respondents acknowledged that sufficient history is gathered on critical components of the cold box and that the information can be accessed at all times as required for future reference. Two (2) of the respondents indicated that no history is gathered and eight (8) respondents did not respond to the question.



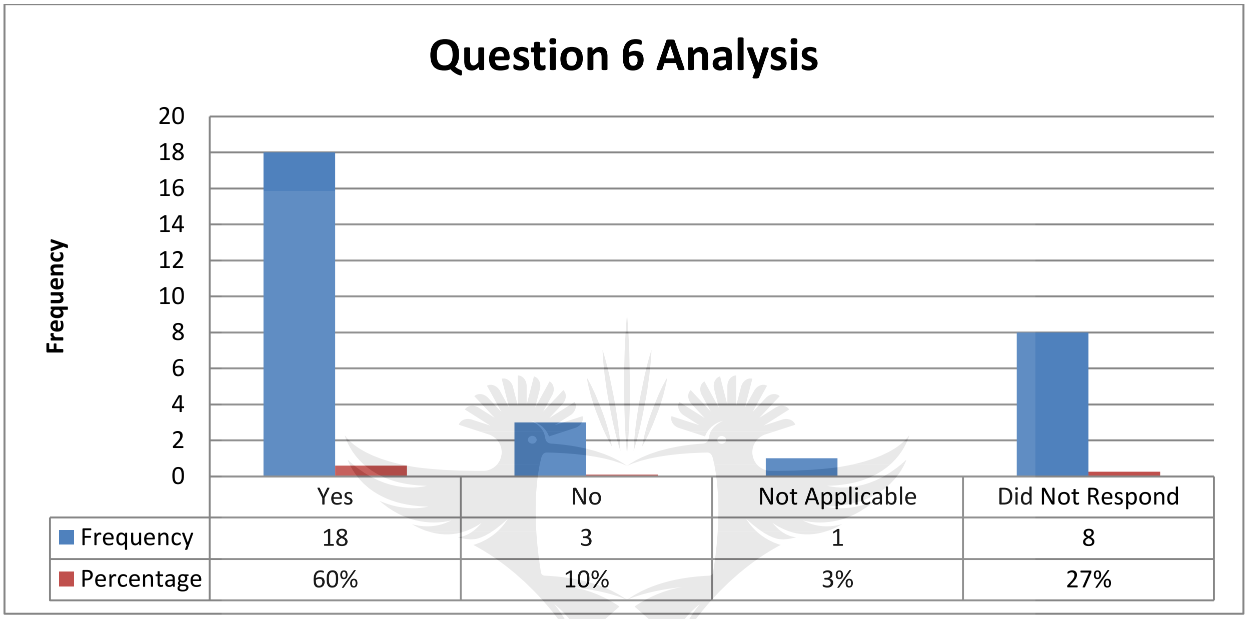
The graph indicates that seventeen (17) of the thirty (30) respondents acknowledged that sufficient maintenance performance record history is gathered on critical components of the cold box and that the information can be accessed at all times as required for future reference. Two (2) respondents stated that no maintenance performance record are stored on critical equipment, three (3) respondents indicated that it is not applicable to their department and eight (8) did not respond to the question.



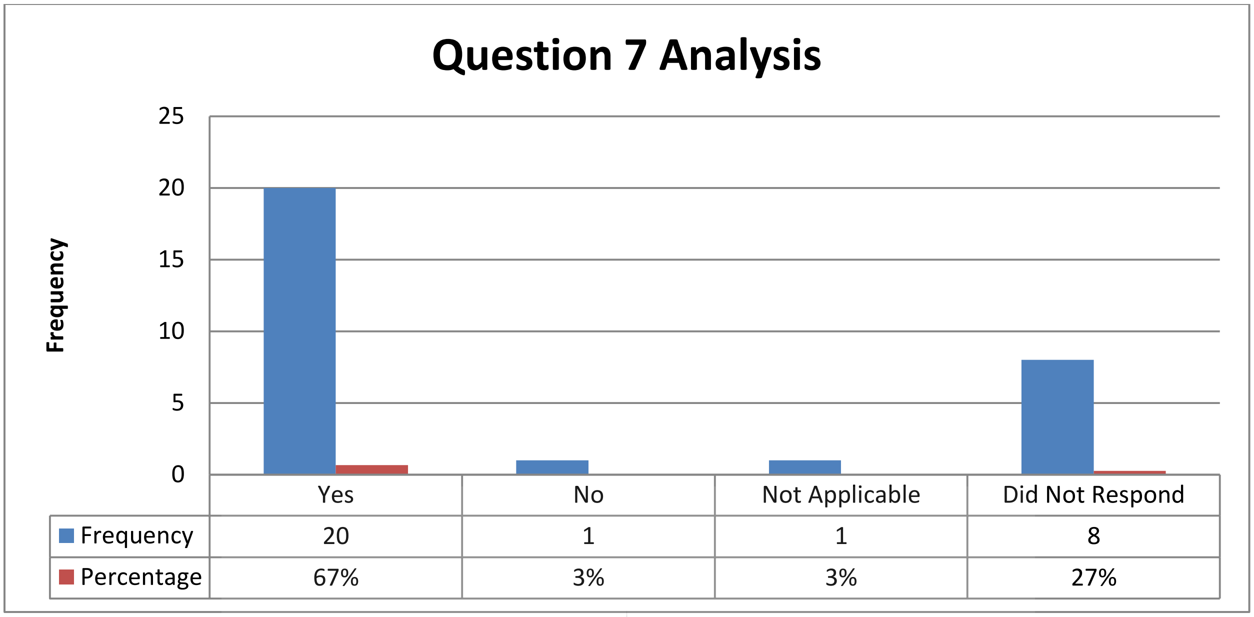
The graph indicates that twenty (20) of the thirty (30) respondents agreed that Sasol make use of a computerized maintenance management system for maintenance planning, tracking and reviewing and two (2) respondents indicated that Sasol does not make use of CMMS in their department. Lastly eight (8) respondents did not respond to the question.



The graph indicates that nineteen (19) of the thirty (30) respondents agreed that the oxygen department in Sasol make use of priority coding when maintenance are being planned, executed and reviewed by the maintenance team performing the repairs on the cold box. Three (3) respondents indicated that the question is not applicable to their field of expertise and eight (8) did not respond to the question.



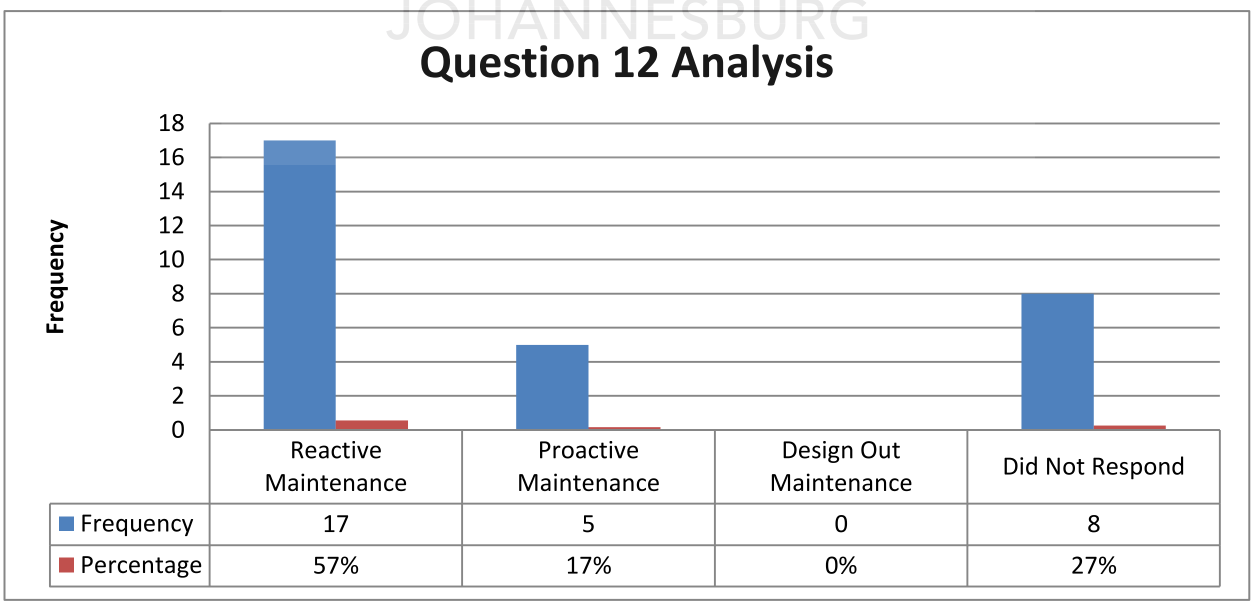
The graph indicates that eighteen (18) of the thirty (30) respondents agreed that the oxygen department in Sasol utilize superintendents, or at least effective supervision to ensure maintenance activities are performed up to standard. Three (3) respondents indicated that no supervision are utilized in the department they work, one (1) respondent indicated that the question is not applicable to his department and eight (8) did not respond to the question.



	Yes	No	Not Applicable	Did Not Respond
Frequency	20	1	1	8
Percentage	67%	3%	3%	27%

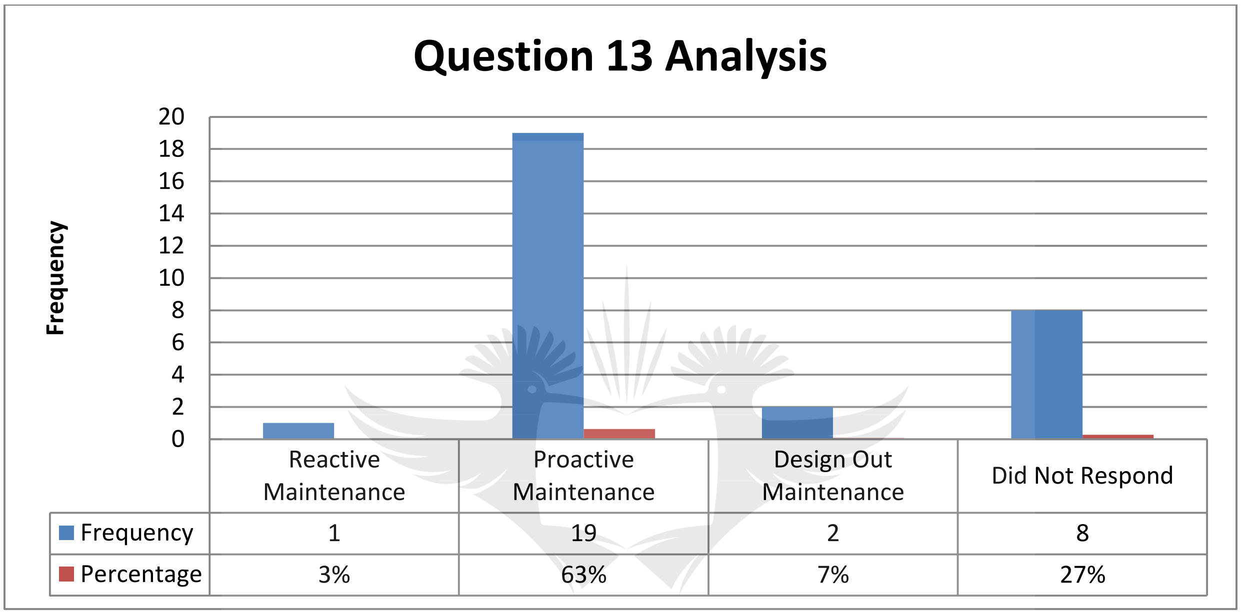
The graph indicates that twenty (20) of the thirty (30) respondents agreed that the oxygen department make use of the services of planners and the planning department to plan and coordinate the maintenance activities for the different departments, conducting the repairs on the cold box. One (1) respondent indicated that no external planners are utilized by this department, one (1) respondent indicated that the question is not applicable to his department and eight (8) did not respond to the question.

Maintenance strategy



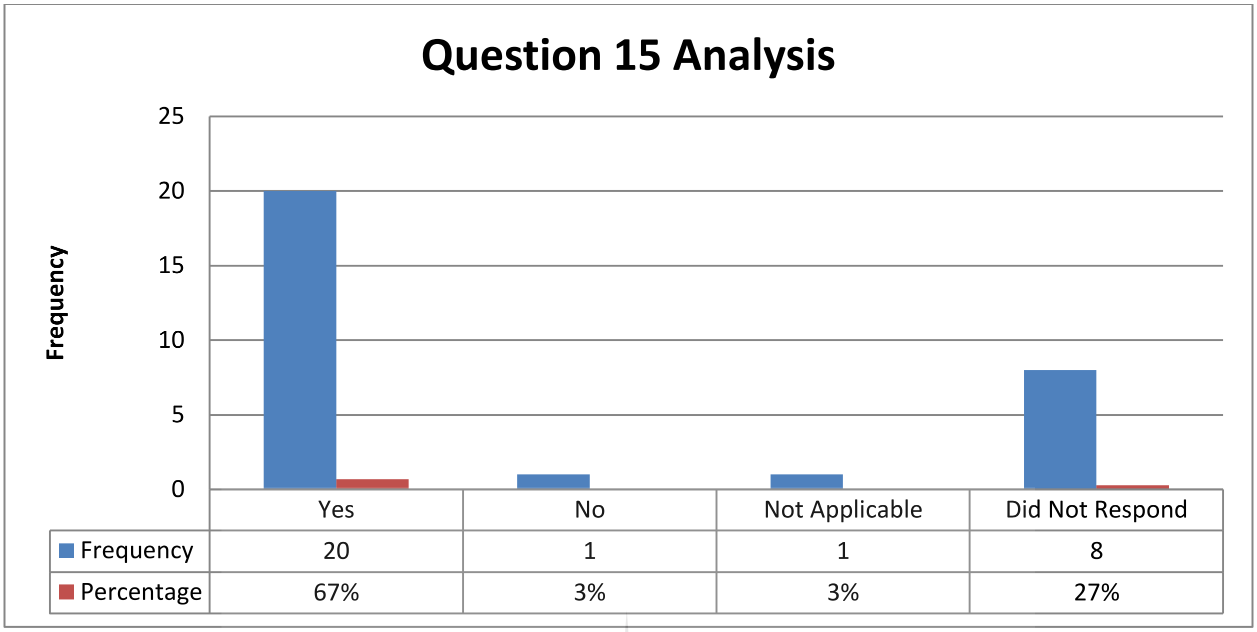
	Reactive Maintenance	Proactive Maintenance	Design Out Maintenance	Did Not Respond
Frequency	17	5	0	8
Percentage	57%	17%	0%	27%

The graph indicates that seventeen (17) of the thirty (30) respondents stated that reactive maintenance is currently practiced on the cold box and five (5) respondents stated that proactive maintenance are currently practiced on the cold box. From the thirty (30) respondents, eight (8) did not respond to the question. Question thirteen (13) is a follow-up question to identify what maintenance strategy the respondents suggest the researcher should implement on the cold box in their opinion.

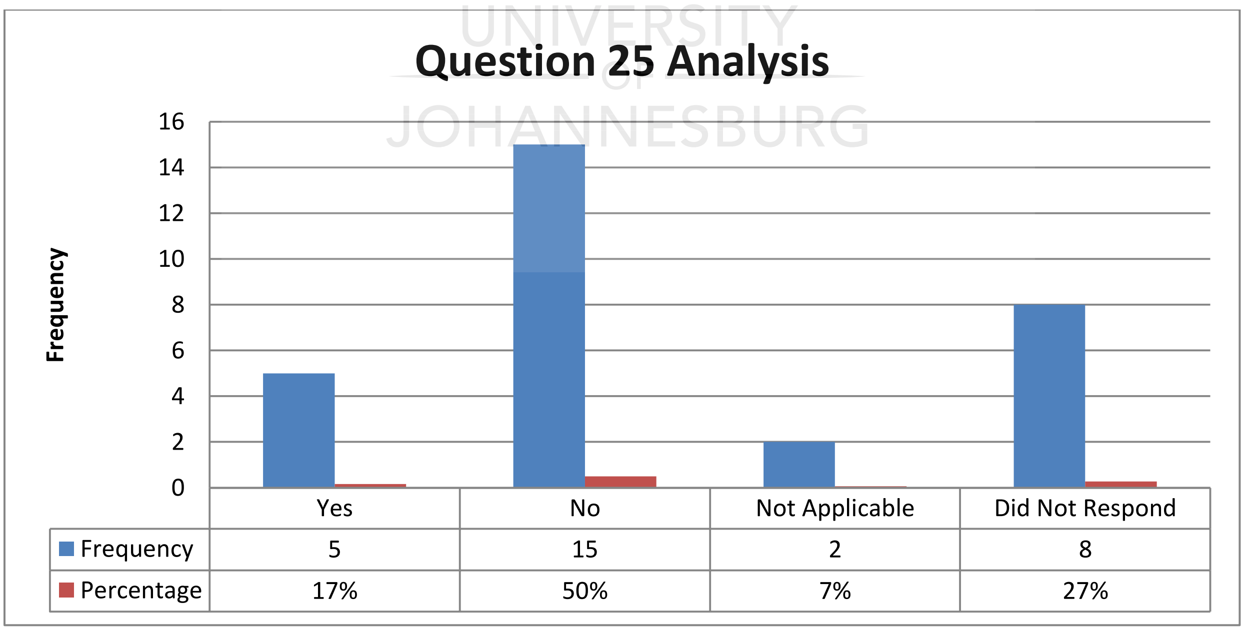


The graph indicates that nineteen (19) of the thirty (30) respondents stated that proactive maintenance is an improvement on the current maintenance strategy that are implemented on the cold box. There is only one (1) respondent that indicated that reactive maintenance is an improvement on the existing maintenance strategy and two (2) respondents indicated that design out maintenance is an improvement in the existing maintenance strategy. Lastly eight (8) of the respondents did not respond to the question.

Question fifteen (15) is asked to identify if techniques are implemented through the different departments to determine the condition of the cold box while the equipment is in operation and what the techniques are. The answer to this question can be scrutinized and evaluated to determine shortcomings in the techniques to improve the stability and reliability of the cold box.

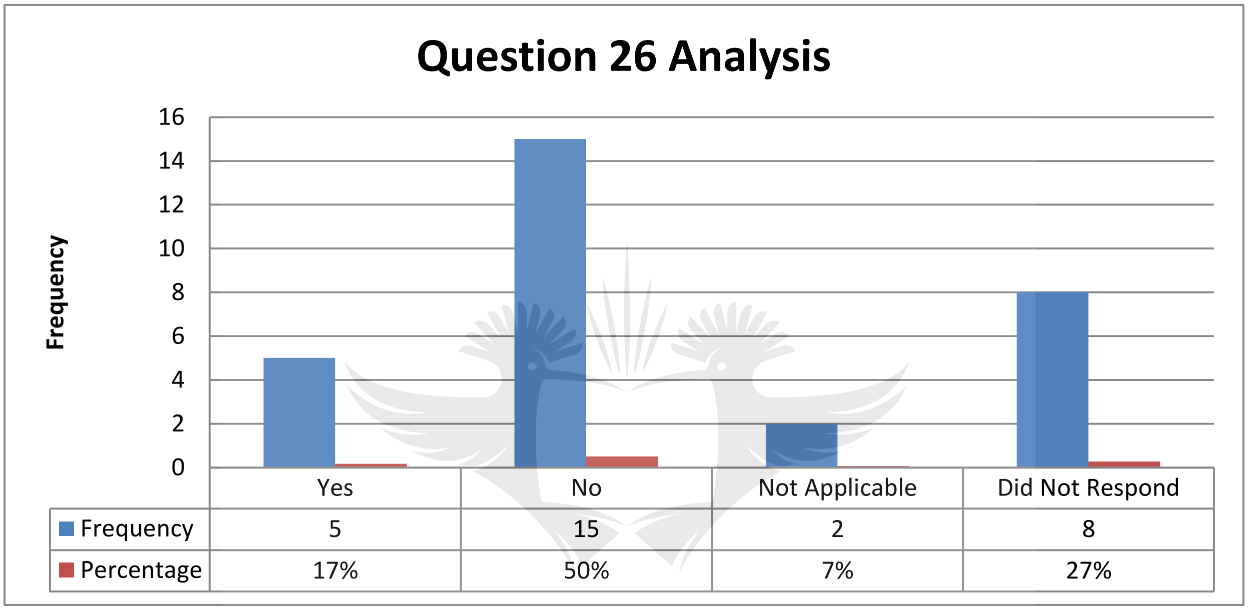


The graph indicates that twenty (20) of the thirty (30) respondents acknowledged that Sasol have active condition monitoring techniques in place to determine the health status of the cold box while it is in operation. One (1) of the respondents indicated that no online monitoring equipment is installed on the cold box and one (1) respondent indicated that the question is not applicable to his department. Lastly eight (8) respondents did not respond to the question.

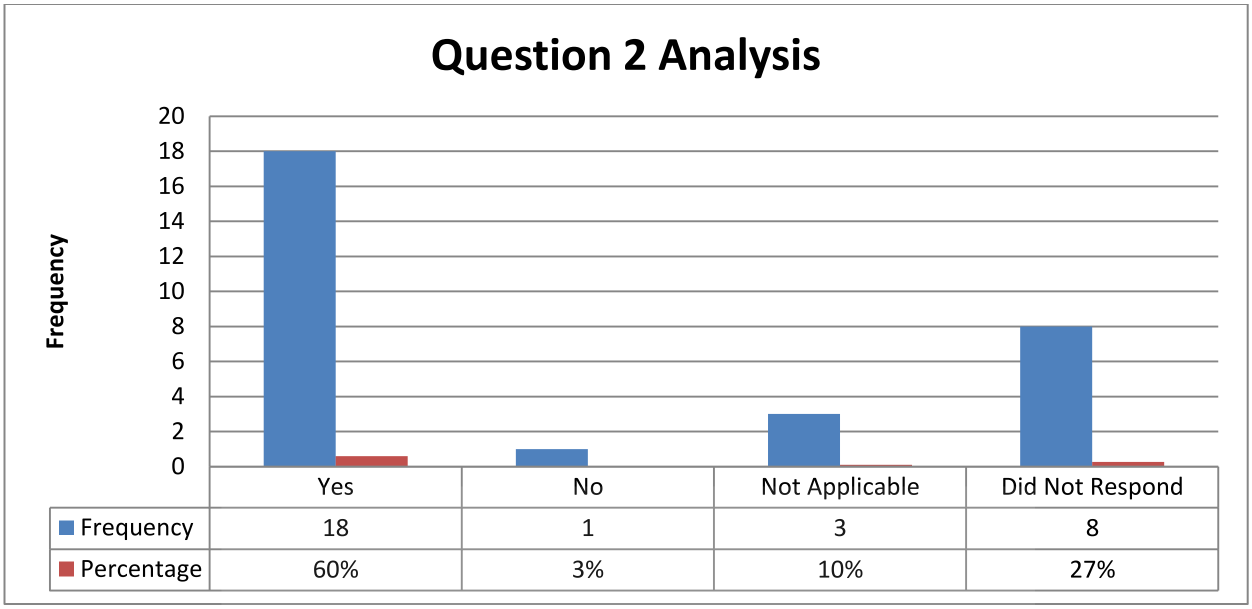


The graph indicates that fifteen (15) of the thirty (30) respondents indicated that no spares are identified and procured prior to the start of the repair process and five (5) respondents indicated that they do order spares prior to the repair process. Two (2) of the respondents indicated that the question are not applicable to their department and eight (8) respondents did not respond to the question.

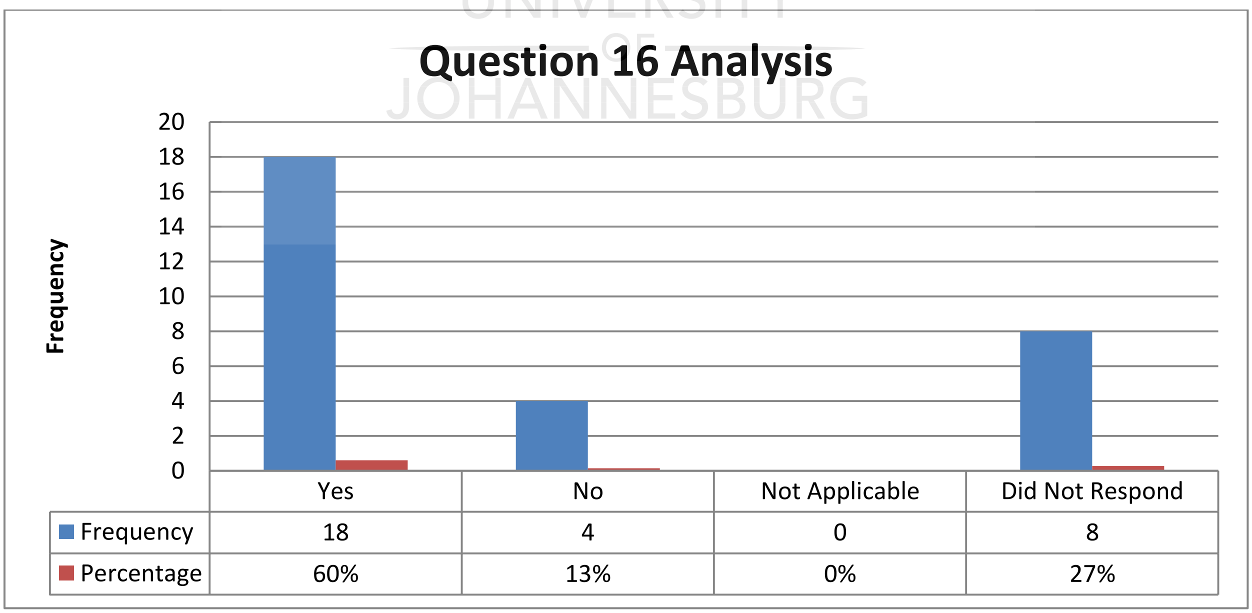
Reliability management



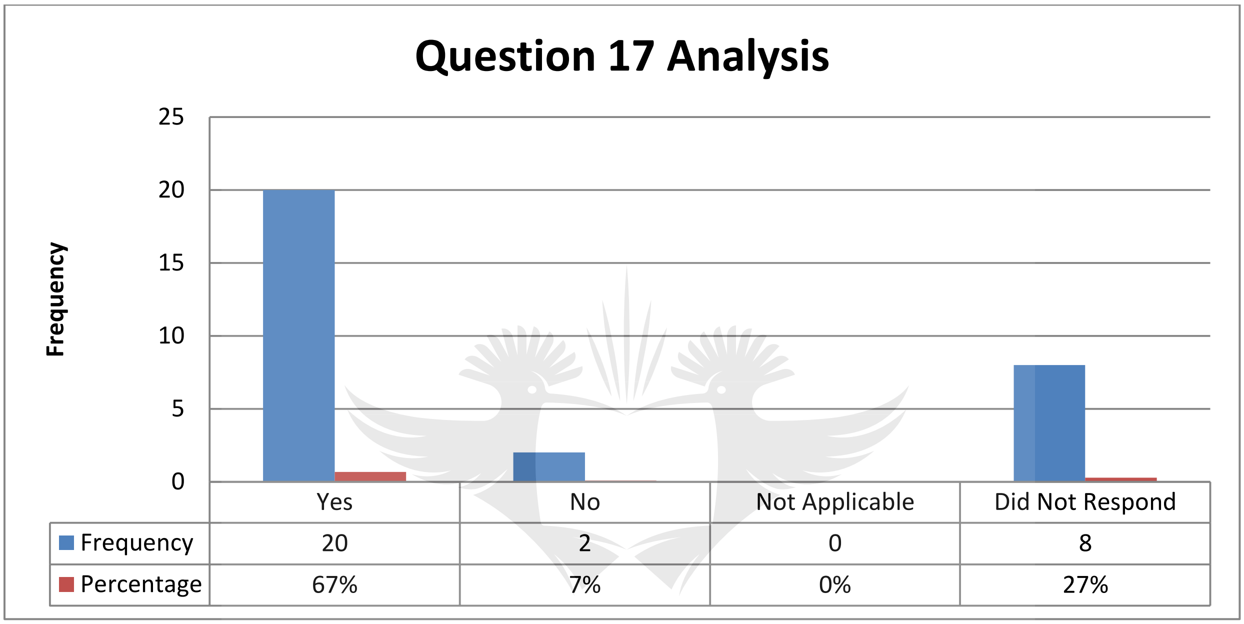
The graph indicates that fifteen (15) of the thirty (30) respondents stated that the current reliability engineering method that is implemented on the cold box, is not sustainable for long term production and five (5) respondents stated that the current method is sufficient for long term sustainability. From the thirty respondents, two (2) indicated that the question is not applicable to their department and eight (8) did not respond to the question.



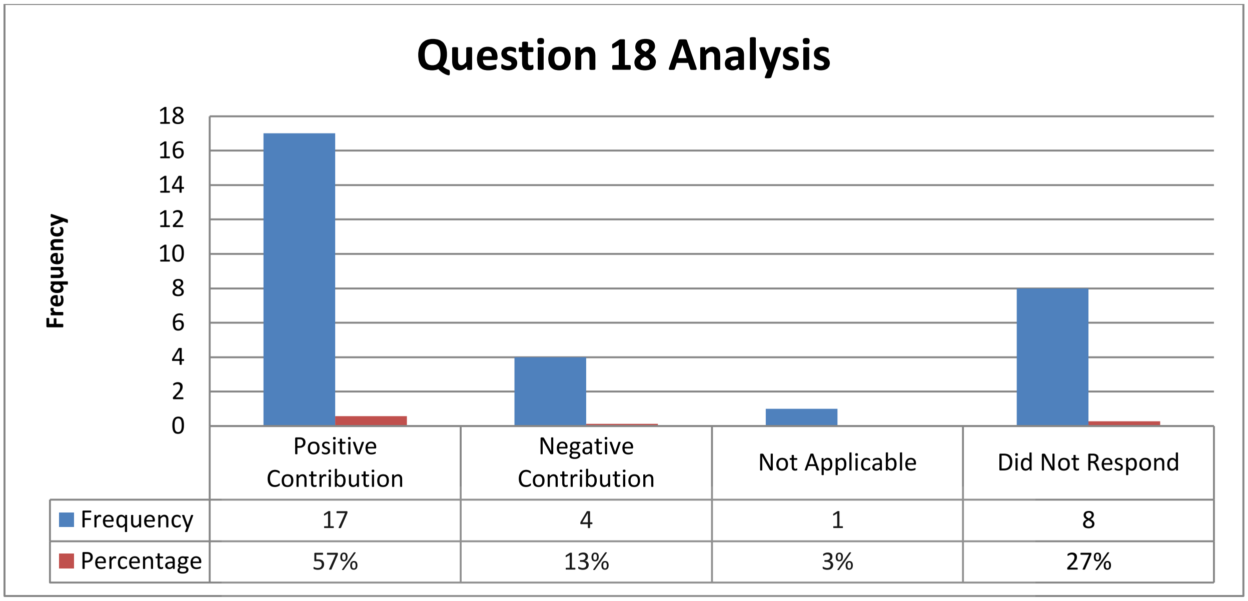
The graph indicates that eighteen (18) of the thirty (30) respondents agreed that conducting online NDE's will contribute to the reliability of the cold box if possible to execute the NDE's. One (1) respondent disagreed that conducting online NDE's will positively contribute to the reliability of the cold box and three (3) respondents indicated that the question is not applicable to their department and field of expertise. Lastly eight (8) respondents did not respond to the question.



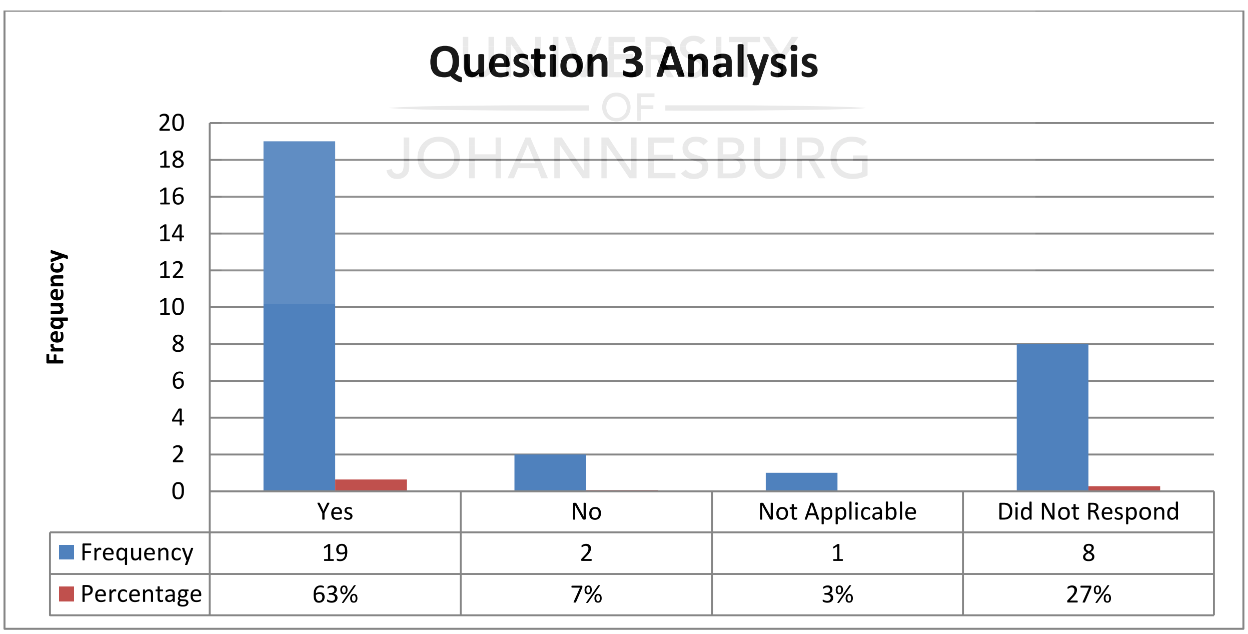
The graph indicates that eighteen (18) of the thirty (30) respondents agreed that additional online monitoring will positively contribute to the reliability of the cold box. Four (4) respondents disagreed that additional online monitoring will make any difference. Lastly eight (8) respondents did not respond to the question. Question seventeen (17) is a follow up question on question sixteen (16), which is asked to identify if it will positively contribute to the reliability of the cold box if the production department regularly do inspections for defects on the cold box.



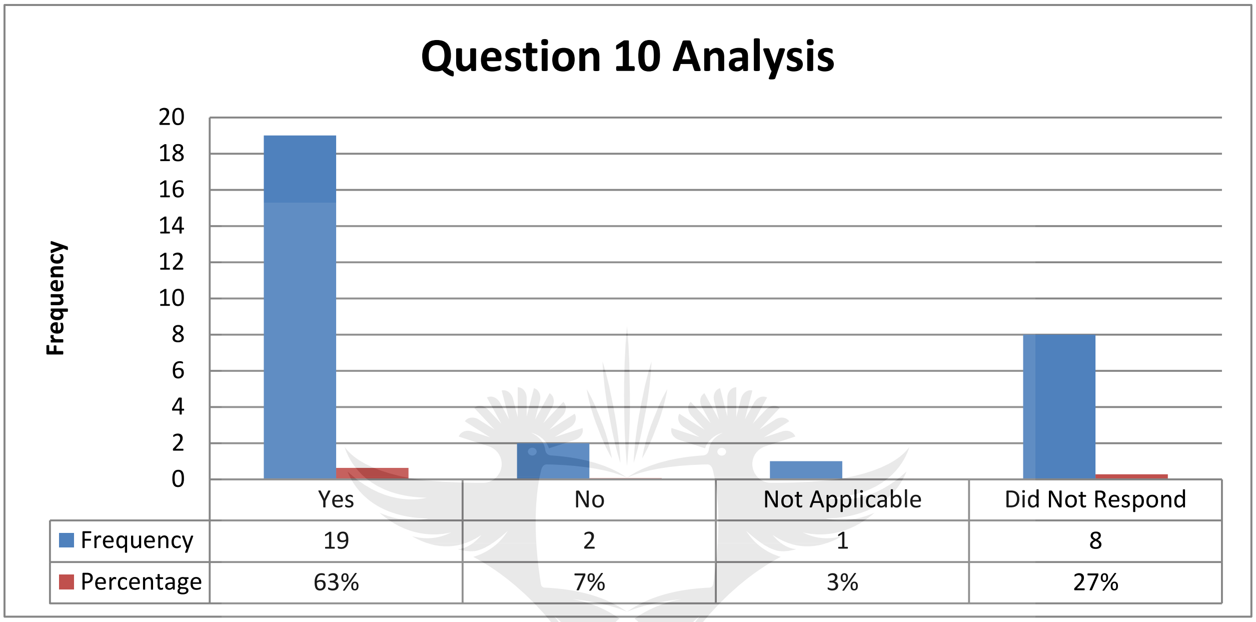
The graph indicates that twenty (20) of the thirty (30) respondents acknowledged that the implementation off additional monitoring inspections for the production department, will positively contribute to the reliability improvement of the cold box. Two (2) of the respondents indicated that active monitoring will not make any difference to the reliability of the cold box and eight (8) respondents did not respond to the question.



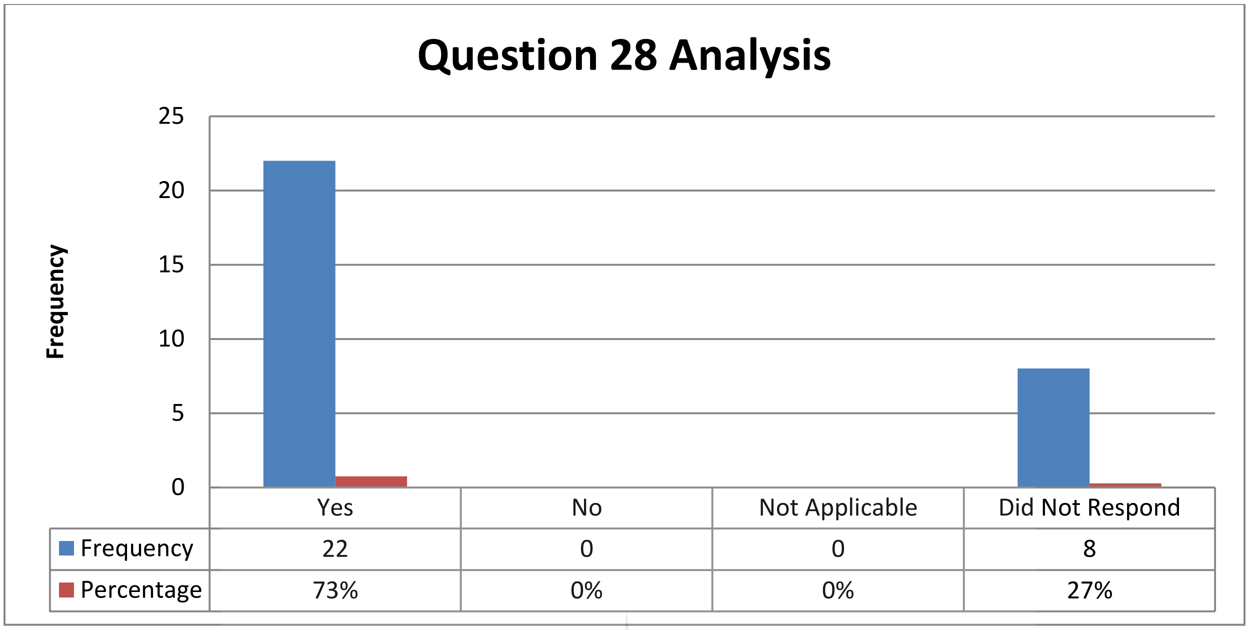
The graph indicates that seventeen (17) of the thirty (30) respondents agreed that thermal scanning on critical components can positively contribute to the improvement of the reliability of the cold box. Four (4) of the respondents disagreed that thermal scanning will make any difference and one (1) indicated that the question is not applicable to his department. Lastly eight (8) respondents did not respond to the question.



The graph indicates that nineteen (19) of the thirty (30) respondents agreed that doing risk based inspections on critical components on the cold box will positively contribute to the reliability of the cold box. Two (2) of the respondents disagreed that risk based inspections will make any difference in the reliability of the cold box and one (1) indicated that the question is not applicable to his department. Lastly eight (8) respondents did not respond to the question.

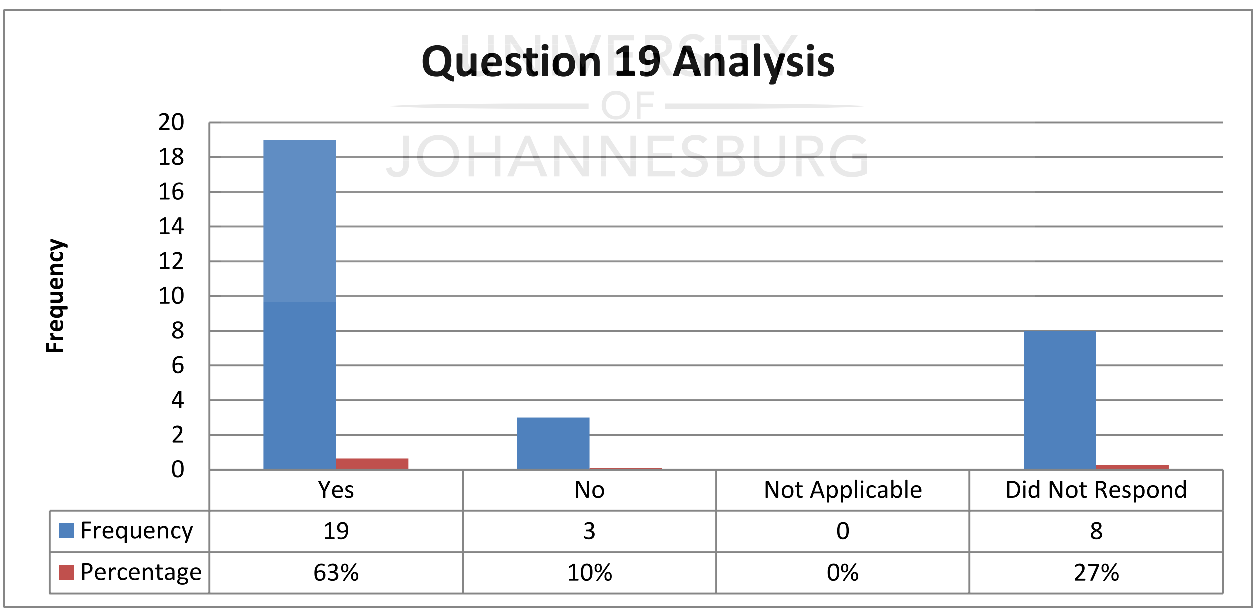


The graph indicates that nineteen (19) of the thirty (30) respondents agreed that Sasol complete a productivity report on completion of repairs on the cold box to compare planned performance to actual performance. Two (2) of the respondents stated that no productivity report is compiled in the oxygen environment and one (1) indicated that the question is not applicable to his department. Lastly eight (8) respondents did not respond to the question.

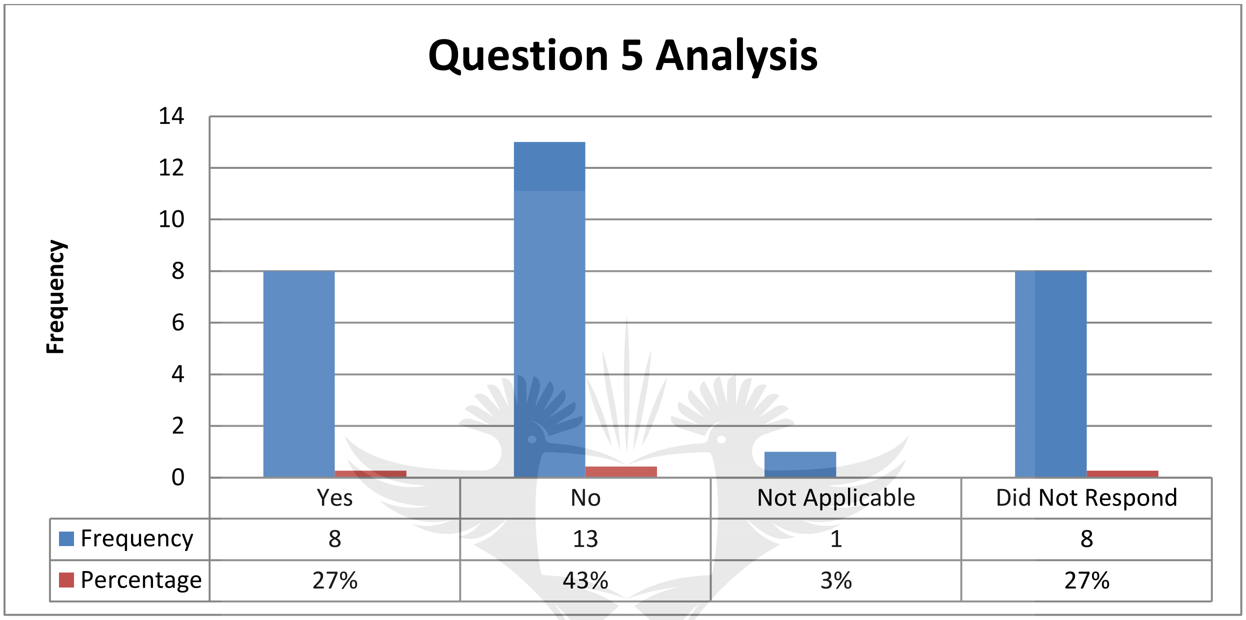


The graph indicates that twenty two (22) of the thirty (30) respondents stated that it is feasible to invest in the improvement of the reliability of the cold box in Sasol and eight (8) of the respondents did not respond to the question.

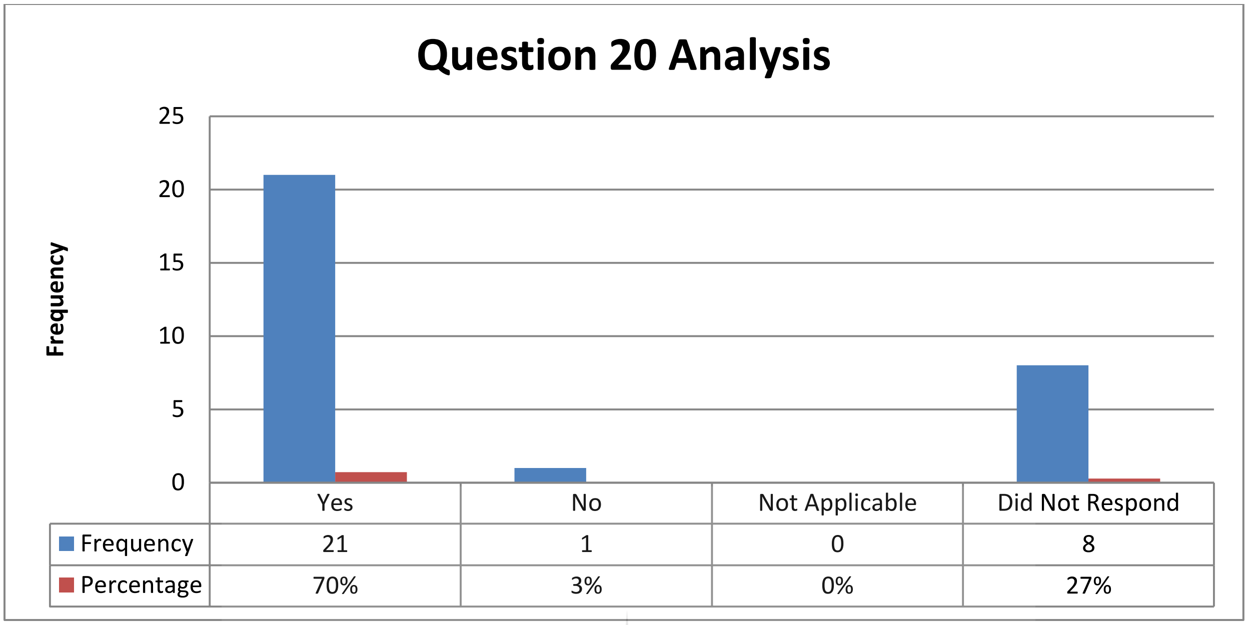
Quality management and the RCM process



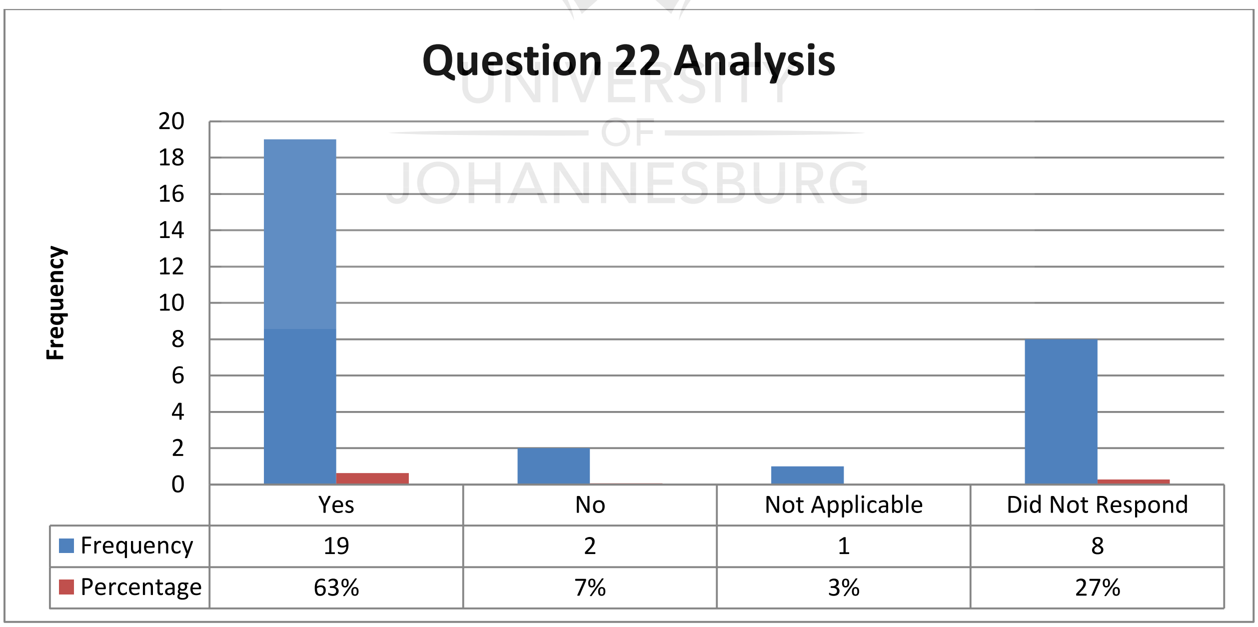
The graph indicates that nineteen (19) of the thirty (30) respondents have identified all critical components on the cold box. Three (3) of the respondents stated that no critical equipment identification was done in their department. Lastly eight (8) respondents did not respond to the question. Question five (5) is asked to ensure that each department has a reference to work from, to enforce a standard throughout the division and Sasol.



The graph indicates that thirteen (13) of the thirty (30) respondents indicated that no inspection check list is available for the cold box to ensure that all departments inspect for reliability improvement mechanisms on the cold box. Eight (8) respondents indicated that they do have inspection check lists and one (1) of the respondents indicated that the question is not applicable to their department. Lastly eight (8) respondents did not respond to the question.



The graph indicates that twenty one (21) of the thirty (30) respondents acknowledged that they analyze the causes off the cold box failures to ensure the same failure do not occur repetitively. One (1) of the respondents indicated that they do not analyze the causes of failure mechanisms at all and eight (8) respondents did not respond to the question.



The graph indicates that nineteen (19) of the thirty (30) respondents agreed that Sasol has a specific maintenance budget for the cold box and all critical components of the cold box to track the cost on each function location. Two (2) of the respondents stated that no budget are allocated for the cold box and one (1) respondent indicated that the question is not applicable to his department. Lastly eight (8) respondents did not respond to the question.

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