The importance of preventative maintenance on flow measurement instrumentation

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Declaration of own work

I hereby declare that this minor dissertation submitted for the partial fulfilment of my MPhil (Engineering Management) degree to the University of Johannesburg is my own work, apart from the help recognized and has not been submitted before.

Abstract

Process plants need to produce more and more to keep up with growing demand. However, these plants are also becoming eroded and dysfunctional due to the lack of maintenance, in this case preventative maintenance (PM). PM is the schedule or periodic checking, to detect the degradation of equipment on a plant. Achieving such maintenance efficiently and effectively is a vital activity to ensure good, safe, and high product quality on a plant. This research considers the technical personnel's perception towards conducting preventative maintenance on flow measuring instruments on their respective plants.

This research looks at the preventative maintenance activities that are required on flow meter instrumentation. It also considers the impact of not conducting such maintenance and the importance of this maintenance as perceived by technical personnel responsible for the plant.

Through literature review, primary preventative maintenance activities are presented. All these activities need to take place in order to keep instruments from failing abruptly in order to avoid degradation, profit losses and to minimize downtime on the process plant. A survey in the form of a questionnaire was distributed using snowball methodology. 101 technical personal in three different industries across the SADC region responded to the questions. Each participant indicated where they were from and they type of plant they worked on. The participant's responses also included if they conducted preventive maintenance proactively or not, as well as the impact of not conducting such maintenance.

It was found that almost half of the technical personnel did not conduct preventative maintenance proactively but rather conducted it reactively. There was also an awareness that there will be an impact on the plant should preventative maintenance not occur. Due to this contradiction, it was therefore portrayed by the technical personnel responding to the survey that preventative maintenance on flow meters was considered unimportant.

As it was established that the perception of preventative maintenance amongst technical personnel is that they do not see it to be important, some future recommendations are presented. These recommendations are that technical personnel should trust in a preventative maintenance system and the processes encompassing this.

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I also acknowledge the work of the authors cited herein and I appreciate the value they add to academia.

Contents

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List of acronyms

CIP	Cleaning in place
HMI	Human machine interface
ILAC	International laboratory accreditation cooperation
MTBF	Mean time between failure
NAMUR[1]	Standardization association for measurement and control
OIML	International organization of legal metrology
P&ID	Pipe and instrumentation diagram
PHM	Proportional hazardous model
PID	Proportional-integral-derivative
PM	Preventative maintenance
SADC	Southern African development community
SCADA	Supervisory control and data acquisition
UUT	Unit under test
WD	Weibull distribution

[1] German

Chapter 1

1 Introduction

1.1 Background

Conducting preventative maintenance on measuring instruments on a process plant has a wide effect on production (Gross, 2002; Pariazar *et al.*, 2008). This preventative maintenance can affect the overall output of the process plant (Gross, 2002; Talabgaew, 2011). Preventative maintenance refers to the regular and routine preservation to help keep equipment and instruments up and running, preventing any unplanned downtime and expensive costs (Gross, 2002). Managers of the system maintenance and technical structures, as well as technical personnel, are trying to improve their organizational processes. In doing so, they are creating a competitive advantage through increasing the quality of maintenance services (increasing effectiveness) and thus reducing the total cost (increasing efficiency) (Yang *et al.*, 2018). Technical preventative maintenance teams continue to push themselves and technical personnel to perform the exact amount of maintenance that is needed, according to the plant needs and system requirements (Parida and Kumar, 2006; Moran, 2015). The exact amount of maintenance that is conducted in the correct time frame, while still allowing for production, will result in a healthier plant (Carnero, 2006; Baker, 2016).

With regards to instrumentation, preventative maintenance is the activity of cleaning, inspecting, performing functional checks and verifications as well as conducting calibrations on an instrument to check that it is operating correctly (Gross, 2002; Altendorf *et al.*, 2003; Khan and Haddara, 2003; Toteva, Slavov and Vasileva, 2017). All these activities are placed together in order to ensure that instruments perform correctly, and these activities contribute to the process of preventative maintenance. These activities are often considered the life line of any plant and are essential (Ma, Sun and Mathew, 2007). Preventative maintenance on measuring instruments are needed by every manufacturer of goods, due to the quality, safety and demands a process plants (Samat, Kamaruddin and Azid, 2011).

However, in the Southern African Development Community (SADC), many process plants experience operational problems. This is often due to the lack of proper and timeous preventative maintenance on the plant (Nyemba and Mbohwa, 2018). Plants can often experience lengthy down time since inadequate preventative maintenance is conducted. A lot of industries in the SADC region have started to deteriorate either due to the time they have been operating without preventative maintenance or the lack of preventative maintenance from the beginning (Samat, Kamaruddin and Azid, 2011; Talabgaew, 2011; Moran, 2015). This may be due to the perceived lack of time, over production, inadequate skills or even willingness (Moeko and Visser, 2013; Nyemba and Mbohwa, 2018). This research paper will explore perceptions of the importance attributed to the need for conducting such preventive maintenance activities and the impact of not conducting such maintenance.

1.2 Problem statement

Preventative instrumentation maintenance is an essential part of every plant's life cycle and maintenance structures (Ma, Sun and Mathew, 2007; Götze *et al.*, 2017). Flow measuring instrumentation maintenance on every part of the plant is essential, to keep the plant in optimal production (Carnera, 2005; Sharma, Debnath and Musa, 2018). Due to a lack of preventative maintenance, plants are becoming eroded and dysfunctional (Talabgaew, 2011). Therefore, preventative maintenance needs to be conducted by technical staff working on the plant. This research will look at the following problem: **Preventative maintenance of flow measuring instruments on the plant is not perceived to be a priority by the responsible technical personnel.**

1.3 Objectives of the study

The objective of this study is to research how technical personnel conduct preventative maintenance, and what effect it may have on the plant. In addition, it will also look at the perceived importance of conducting preventative maintenance and what solutions could be put in place to change this perception. Many companies state that preventative maintenance on instrumentation will keep the plant running and if done correctly will yield a high 'success' rate (Gross, 2002). The research will reveal that preventative maintenance is perceived as unimportant and is conducted less efficiently and effectively. This may also reveal that certain companies operating in the SADC region could need to look at their timeous proactive preventative maintenance processes.

1.4 Research Questions

This research aims to answer the following questions in order to achieve the objectives of this study;

RQ1: What are the preventative maintenance activity practices required on a flow measuring instruments in a plant.

RQ2: What is the impact on the plant should preventative maintenance activities not take place on flow measuring instruments.

RQ3: Is preventative maintenance on flow instrumentation perceived as important by the technical personnel.

1.5 Scope

This research looks at the importance of preventative maintenance on measuring instrumentation in the process plant sector, with a specific focus on four main sectors within Southern Africa (SADC). These four sectors are mining, minerals and metals; oil and gas; food and beverage and water/wastewater plants. The research will describe why it is important to complete a certain amount of preventative maintenance, and the impact of this, but also what the perception of this kind of maintenance is amongst the employees expected to conduct it.

Data was collected by means of a quantitative questionnaire survey that was sent out via snowball methodology to the maintenance employees in such industries. From these questions a conclusion was made to see whether preventative maintenance is occurring; the perceived impact and the perceived importance behind conducting such preventative maintenance.

1.6 Research Design

The research will commence with a literature review, with topics ranging from instrumentation maintenance and the activities part of it, as well as the impact of not conducting preventative maintenance. It will also look at the importance of conducting such maintenance as perceived by technical personnel.

In terms of obtaining data to give answers to the questions a survey will be sent out to technical staff on different plants via snowball methodology. This will be in the form of an online questionnaire method to employees. Artisans, technicians, engineers and maintenance managers, which from part of technical personnel will answer a set of specific questions. The questionnaire will be yes/no questions, or a basic multiple choice. The results will then be presented and analysed, and conclusions will be drawn from this in combination with reviewed literature.

1.7 Document Layout

Chapter 1 introduces the research as well as the research problem by giving it some context. The research questions and objectives are presented and highlight the problem that will be solved. Towards the end the research design is described where the methodology is discussed.

Chapter 2 investigates what are the best preventative maintenance activities required on flow measuring instruments. It starts by looking at different mathematical models that are used in preventative maintenance systems. It considers the best activities that need to be adhered to for flow measuring maintenance. It looks at the consequences on the plant if no such maintenance is conducted and, finally, explores the attitudes towards preventative maintenance amongst technical personnel.

Chapter 3 considers the research methodology, used to conduct the research. It describes how the questionnaire was formatted and distributed. It explains how the data was collected, analysed and presented.

Chapter 4 presents the results from the survey and makes a comparison of the figures through data analysis.

Chapter 5 deliberates on the results presented in chapter 4 in conjunction with the literature review. It offers recommendations and draws conclusion based on the results.

1.8 Conclusion

The perception of the importance of conducting preventative measuring instrumentation maintenance in the SADC region is investigated. As plants need to produce more and more to keep up with demand, technical teams need to conduct preventative maintenance on instrumentation more often. However, it is critical to understand if this maintenance is perceived as an important activity by the technical personnel conducting it.

Chapter 2

2 Literature Review

2.1 Introduction

This chapter will explore the guidelines, activities and consequences of maintenance. It will specifically look at preventative maintenance (PM) on process plants and the consequences when not conducting such. The principal focus of the literature review will be to consider flow meter instrumentation and preventative maintenance activities surrounding this. The review will also consider the consequences of not performing such preventative maintenance on flow meters in a process plant.

With the focus of this literature review being on process plants, maintenance and flow instrumentation one needs to understand these three initial concepts. Process plants, electric or even pneumatic, are where a kind of procedure takes place to create value (Moran, 2015). The plant's primary goal is to produce a value product by using different processes (Moran, 2015). Process plants can fall into a few categories such as food and beverage plants, water and wastewater treatment plants and even different electrical generation plants (Moran, 2015). All these different process plants rely on instrumentation as the "eyes and ears" of the plant. Flow meter instrumentation values are included in this reliability, especially the accuracy of them, so the plant continues to operate according to specification (Gross, 2002; Moran, 2015).

A flow instrument is a device that can measure the flow of product (gas or liquid) and can extrapolate a value in mass or volume (Altendorf *et al.*, 2006). Some examples of flow meters are velocity, mass, differential and positive displacement meters (Cartas *et al.*, 2001; Altendorf *et al.*, 2006). The value measured by the flow meter is often fed to a system of measurement for recording, batching, mixing and control (Altendorf *et al.*, 2006). This value can often be critical in running and ensuring adequate profits from a process plant (Gross, 2002; Upp and LaNasa, 2002). It is then highly recommended that these instruments need to be maintained thoroughly, timeously and properly on plants (Upp and LaNasa, 2002).

On process plants, flow meters need to be maintained. Maintenance is the process of preserving something so it continues to remain as close as possible to its original state (Samat, Kamaruddin and Azid, 2011). Maintenance can increase the productivity of plants by lowering the failures of equipment with the assurance of increased safety and uptime (Parida and Kumar, 2006; Samat, Kamaruddin and Azid, 2011; Talabgaew, 2011). Accomplishment of such maintenance is a vital activity to ensure good, safe, and high product quality conditions in a plant (Samat, Kamaruddin and Azid, 2011). The effectiveness and usefulness of a maintenance structure play a pivotal role in the process plant's success (Parida and Kumar, 2006). While there are many types of maintenance, such as reactive maintenance (maintenance conducted when an instrument fails (Swanson, 2001)) and predictive maintenance (the prediction of maintenance an instrument needs in the future (Carnero, 2006)), preventative maintenance on flow meters will be a focal point, and thus this will be explored.

This chapter will therefore look at the following topics:

- The definitions and systems of preventative maintenance.
- Preventative maintenance activities on flow instruments.
- The impact of not conducting preventative maintenance activities on flow instruments.
- Views on the importance of preventative maintenance activities.

2.2 Preventative maintenance

Preventative maintenance (PM) is the scheduling and periodic checking, to detect the degradation of equipment on a plant (Moghaddam and Usher, 2011). Gross (2002) defines it as regular, routine upkeep to help retain equipment from unanticipated failure. This also insures instruments are up and running, preventing any unplanned downtime and expensive costs (Gross, 2002). The purpose of preventative maintenance is so that the plant can remain as close to its original state as possible (Samat, Kamaruddin and Azid, 2011). Preventative maintenance can provide an increase in quality, safety and availability in the process plant (Carnero, 2006). In a flow instrument, adjusting and verifying the parts to prevent failures in order to maintain the sustainable life span contributes towards this preventative maintenance (Talabgaew, 2011). An established operation is needed on a plant to avoid failure or degradation in their process conditions. Preventative maintenance allows for this, by using measured trend parameters and routine work (Al-Mishari and Suliman, 2008).

Preventative maintenance activities run into three different phases: first is planning, followed by a trial run, and then execution (Cheng, Chen and Guo, 2007). Planning is related to the interval timing required in order to conduct this preventative maintenance in the appropriate manor. Validation techniques are based on the plan. Once this plan is established a trial run takes place which can be adapted while the process that this change affects is continuing. The last phase of preventative maintenance is execution of the plan (Cheng, Chen and Guo, 2007; Natalinova, Ilina and Frantcuzskaia, 2016). In the planned execution of these activities, there are five different methodologies for flow meter preventative maintenance (Khan and Haddara, 2003; Alhamad, Alardhi and Almazrouee, 2015). These are visual inspection, cleaning, verifications, functional tests as well as calibrations (Altendorf *et al.*, 2003; Natalinova, Ilina and Frantcuzskaia, 2016; Toteva, Slavov and Vasileva, 2017). However, before the technical personnel which are responsible for this work can execute, it is important to plan and trial when and how the work will be performed. This can be completed by using timing techniques as well as validation approaches.

2.2.1 Interval timing of preventative maintenance

Good timing in measurement instrumentation is only made possible by proper instrument preventative maintenance. Preventative maintenance such as calibration adjustment is one method to maintain the metrological reliability of a measuring instrument (Natalinova, Ilina and Frantcuzskaia, 2016). Companies use it at regular intervals, so-called calibration intervals. Natalinova, Ilina and Frantcuzskaia (2016) mention that the calibration interval was adjusted and calculated in the potentiometers to optimize the life cycle of the instruments. The authors also mentions that there are some critical factors which can affect the adjustment of calibration and maintenance interval, like the stability of the equipment, criticality, environmental conditions, which mode of measurement is being used and the setting of initial calibration intervals (Natalinova, Ilina and Frantcuzskaia, 2016).

Time-based analysis is also used for the analysis of periodic time spent on projects (Verhagen and De Boer, 2018). This analysis is done regarding various preventative maintenance factors. Dynamic programming, a time-based analysis, is one of the optimization methods based on a mathematical model and has the tendency to convert complex problems into simpler ones. In the past, it is seen that research has been conducted on the impact of dynamic programming for reducing cost, proper schedule and to obtain a solution in emergency maintenance (Wildeman, Dekker and Smit, 1997). Researchers have also used proportional hazard model (PHM) as well as Weibull Distribution (WD) for the calculation of optimal preventative maintenance intervals (Kobbacy, Fawzib and Percya, 1997; Duarte, Craveiro and Trigo, 2006). These methodologies, as they are time based, also take into consideration the age of the plant as well as the age of the specific instrument. The older the plant or the instrument the higher the change in frequency of preventative maintenance (Duarte, Craveiro and Trigo, 2006).

The International Organization of Legal Metrology (OIML) and International Laboratory Accreditation Cooperation (ILAC) are international organizations which introduced methods for defining calibration and preventative maintenance intervals for technical devices for monitoring and measurement. These organizations state that various types of preventative maintenance need to occur at a certain interval of the life span of equipment and instrumentation. This interval timing is often given by a measuring management system placed on the proves plant (*ISO 10012:2003(en), Measurement management systems — Requirements for measurement processes and measuring equipment*, 1997). The algorithmic method does have its advantages as it is more manageable and has less chance of rejection, until rejection is based on statistical data (Litchfield, Javernick-Will and Maul, 2016). Changes are often required while determining the calibration interval of technical devices for monitoring and measurement. (Toteva, Slavov and Vasileva, 2017). Alhamed, Alardhi and Almazrouee (2015) talk about the development of a genetic algorithm method which schedules preventative tasks. This methodology was implemented in generation and desalination units of co-generated plants. Results showed that the generic algorithm is a powerful technique for scheduling preventative maintenance and can be implemented for any type of plant, however it does not regard any type of instrument or equipment (Alhamad, Alardhi and Almazrouee, 2015).

There are various types of interval timing methods that can be seen in this context when reviewing literature. Many methods are challenging to implement in industry, especially in ‘poorer’ manufacturing facilities, since they require large cost and technical human resources (Nakaya and Yoshizumi, 2019).

There are many timing methodologies and algorithms developed by different industries and technical responsible individuals. These interval timing procedures play a vital role in conducting preventative maintenance and need to be implemented correctly. However, this timing as well as the activities need to be validated. There are various validation techniques available and developed in order to confirm whether the timing and the activity are performed correctly.

2.2.2 Validation techniques for preventative maintenance

There are different validation techniques used in process plants to verify that the correct maintenance methodologies and timings are being developed and used. The Monte Carlo simulation is a method based on the simulation model, used to determine preventative maintenance time, cost and rate of deterioration (Gilardoni *et al.*, 2016). The probability density function is another mathematically based model which determines preventative maintenance, maintenance time and cost (Ben Mabrouk, Chelbi and Radhoui, 2016). Hip-Hop analysis, Markov method, Integer programming and Life cycle costing are some of the other methods for optimization of replacement costs. The Markov method determines preventative maintenance cost, time and quality (Nourelfath, Nahas and Ben-Daya, 2016). The focus of these methods is to check the effects of preventative maintenance on system reliability, cost replacement and maintenance policy implementation (Korpi and Ala-Risku, 2008; Nggada *et al.*, 2010; Chang and Lo, 2011)

For optimization of inventory spare parts, proportional hazard method Monte Carlo simulation and risk matrix are known methods for the intervention of preventative maintenance (Dalgic *et al.*, 2015; Rigamonti *et al.*, 2016). When optimization of preventative maintenance is coupled with repair, the probability density function method is used with a focus on failure rate reduction, reliability, maximum profit of leased equipment as well as a threshold value of failure rate (Yeh and Chang, 2007; Yeh, Kao and Chang, 2009; Chang and Lo, 2011).

With the advancement in manufacturing industries and using a high level of complex machines, high cost of maintenance is also seen. All role players in the market are wanting to improve their productivity. To overcome this problem, one solution is to increase the operational availability of machines which in turn will lead to increased productivity. A study by Kolte and Dabade (2017), analysed methodologies in the context of preventative maintenance on a wastewater treatment plant. The faults and breakdown in critical parts of machines were identified and analysed. Different tools like root cause analysis and fish bone diagram were implemented for the identification of the actual cause. The findings showed that the implementation of preventative maintenance on critical machines can lead to an increment in machine availability and also reduce machine failure rates (Kolte and Dabade, 2017).

Data acquisition of machinery breakdown from plants in the manufacturing system is of great importance as it can lead to an improvement of future actions. Basri, Tiek and Kamaruddin (2014) conducted a case study in a semi-conductor company with two manufacturing plants. The focus was on a plant involved in assembling electronic circuits for the implementation of preventative maintenance where problematic machines were identified. The next stage was failure analysis, in which a tree diagram tool was used to determine the maintenance requirement. The findings of this research are helpful in developing techniques to gather data and show that future preventative maintenance planning and validation is critical (Basri, Tiek and Kamaruddin, 2014).

Researchers have also designed a preventative maintenance schedule based on the failures of a single component system with multiple units (Al-Mishari and Suliman, 2008; Moghaddam, 2013). These failures are responsible for the faster deterioration of a system. The effect of a critical accumulator was seen on the deterioration of the mechanical seal. Repair rates and failure were two parameters for the formulation of an equation model. An optimal plan for preventative maintenance was designed with the help of regression analysis (Al-Mishari and Suliman, 2008).

Rachiotis (2008) presented a decision-making model for optimization of preventative maintenance with replacement and time. The aim was to increase the system's performance by finding new reassembly policies (Rachaniotis and Pappis, 2008). It was a mathematically based model using mixed integer linear programming. Moghaddam (2011) presented another mathematically based model, with the focus to determine the schedule component replacement of machines (Moghaddam and Usher, 2011).

All these methods and modules point to one outcome, that preventative maintenance needs to occur regularly or else a plant will not run optimally over time. This will also lead to degradation and loss of profits if preventative maintenance is not conducted timeously and when necessary. In most cases a maintenance system can either be purchased or the technical personnel can calculate the required frequency and maintenance required. This frequency, as well as mathematical models, increase the efficiency and effectiveness of preventative maintenance on the plant.

2.3 Preventative maintenance activities on flow instruments

The discussed methodologies above allude to the timing of preventative maintenance (PM) as well as validation techniques. Both are important factors in conducting preventative maintenance activities. Timing of preventative maintenance can be provided by a PM system often using the above-mentioned models and analysis to determine when to conduct maintenance. However, what has also come to the foreground, is the actual activities needed to perform preventative maintenance on plants. Certain critical activities are needed during the preventative maintenance schedule (Baker, 2016; Toteva, Slavov and Vasileva, 2017). These activities on flow meters, follow a sequence of preventative events to ensure the instrument is kept as close as possible to its original state (Natalinova, Ilina and Frantcuzskaia, 2016). The PM activities include visual inspection, cleaning, a functional test, verifications as well as calibration. The description of these activities will be presented in the following sections.

2.3.1 Visual inspection

A visual inspection is the act of viewing the device feedback by observing its condition (Khan and Haddara, 2003). There are two ways of performing this visual inspection (Kuboki and Takata, 2019):

- A walk around visual inspection, which is the most common, by human operators.
- In-line monitoring by fixed sensors, which, with recent technology, can be done through the NAMUR (standardization association for measurement and control)

standard on the SCADA (supervisory control and data acquisition) system (Birkenkamp, 2009).

The information provided by the system or by human operators is then captured and assessed (Grieb, Linzenkirchner and Theilmann, 2005). The information that is recorded could vary from installation, physical damages (e.g. dents) or standard display faults (Grieb, Linzenkirchner and Theilmann, 2005).

An important factor in an inspection is to check if the instrument is "clean" enough to continue safe and accurate operation. If it is not, an action must take place (Wang *et al.*, 2010). This will often be indicated by four different standard messages through in-line monitoring. These four different standard messages that can be found on the flow instrument display or on the Human Machine Interface (HMI) if this is available (Grieb, Linzenkirchner and Theilmann, 2005). The flow instrument could be displaying the following standards:

- Good condition
- Failure
- Check Request
- Function check

An action (or none) is developed from the visual inspection so other activities can take place if necessary (Grieb, Linzenkirchner and Theilmann, 2005). Preventative maintenance decisions should be made after the inspection has been carried out (Wang *et al.*, 2010). Visual inspection should be carried out as often as possible according to a maintenance scheduled plan and allocated costs as eluded to in Interval timing of preventative maintenance and Validation techniques for preventative maintenance. As long as an appropriate method is selected and followed, inspection of flow instrumentation will hold its benefit (Kuboki and Takata, 2019).

2.3.2 Cleaning of instruments

Upon the completion of a visual inspection as above, cleaning of the instrument also becomes essential. Cleaning an instrument is a critical factor in prolonging the instrument's life, and is an essential operation for many process plants (Wilson, 2005; Cheng, Chen and Guo, 2007). Cleaning is the removing of a deposit layer or build up from the equipment's external and measuring surfaces. This activity takes place so the instrument can be maintained and operate. Cleaning techniques are categorized into two methods: physical and chemical automatic (Wilson, 2005).

- The chemical automatic method includes some of the following:
  - Cleaning in Place (CIP) or Pigging are automatic ways of cleaning certain flow instruments in different industries. These industries include the food and beverage industry and the oil industry (Mostafa, Dumrak and Soltan, 2015).
  - With new technology there are some flow instruments that can clean themselves in certain applications (Wilson, 2005; Splatt and Puerto, 2006).
  - Spray systems and high pressure jets covering internal and external surfaces in order to clean the flow instrument and any build up that may occur are also used (Morison and Thorpe, 2002; Wilson, 2005).
- Physical cleaning is the method of taking the meter out of the process and cleaning it. If the device is taken out and cleaned by hand, this could be due to the sensitivity of certain components. The meter could be cleaned by hand or sometimes using different finger machinery (Wilson, 2005). This machinery could be a steam system, electronic dry cleaning or high-pressure air. Hand cleaning is often used in combination with the machinery and in addition the instrument is carefully hand brushed or wiped (Wilson, 2005).

Although both methods can be time consuming in terms of PM activities, cleaning is an essential activity, and adds value to other preventative maintenance activities (Wilson, 2005).

2.3.3 Functionality Test

A functionality test is conducted by checking how the instrument is operating in the field and if it is operating as expected by the process (Alhamad, Alardhi and Almazrouee, 2015). A flow instrument needs to be checked regularly in order to confirm that it satisfies the requirements set by the process operations (Toteva, Slavov and Vasileva, 2017). This helps in the operation of the plant and in preventing larger consequences of errors in the future. Nyemba and Mbohwa (2018) suggested that functional checks and tests are performed on a regular basis to increase sustainability of plants. A functional test may also indicate if the flow meter needs to be repaired or not as it may not be performing to specification set out by the process plant (International Organization for Standardization, 2006).

A functional test can often relate directly to calibration tests. The functional test should often be performed before a calibration procedure is executed (International Organization for Standardization, 2006).

2.3.4 Verification

A verification is performed by checking that all the internal electronics as well as the measuring sensor are functioning correctly (Toteva, Slavov and Vasileva, 2017). This is often carried out by an external verification tool that is connected to the flow meter. In this activity process diagnostics and prognostics are examined and are an important part of the verification (Hashemian, 2010).

There are two components practiced in terms of performing verifications on a flow meter. Firstly, on the internal electronics and sensor and secondly using an external flow meter (Natalinova, Ilina and Frantcuzskaia, 2016).

- On the internal electronics and sensor of a flow meter a simulation of a calibration reference point is carried out. The external tool observes a system response against this reference. This response is then compared to the internal electronics and sensor specifications set out in the design of the flow meter. This can be quite a quick process and can have relative accuracy (Roughan and Doorhy, 2009).
- The external verification on the flow meter can be performed by using another flow meter (e.g. clamp-on ultrasonic) in line with the unit under test. This comparison is performed and the flow sensor is compared to an external reference system (Roughan and Doorhy, 2009).

Each of these methods has its respective place and appropriate application, depending on the flow meter and the installation. It will also relate to the visual inspection and function check performed (Natalinova, Ilina and Frantcuzskaia, 2016). A verification is an effective and quick way to validate a flow meters performance before it is necessary to take further maintenance steps (Roughan and Doorhy, 2009).

2.3.5 Calibration

Flow calibration is an important part of metrology, and flow calibration facilities which are the traceability system of flow measurement, play an important role in production and maintenance (Lei *et al.*, 2011; Toteva, Slavov and Vasileva, 2017). These calibrations need to occur in order to maintain production in a plant and good preventative maintenance (Coble *et al.*, 2012). This activity often takes place with a functional test and/or verification and may also indicate the flow meter needs (International Organization for Standardization, 2006).

A calibration is comparing the flow measuring unit to a traceable standard, using for example ISO 9001 (*ISO 9001:2015(en), Quality management systems — Requirements*, 2015) and sometimes performing adjustment within a prescribed tolerance (Coble *et al.*, 2012). In performing a calibration, intrusive techniques, such as isolating the unit from the system through physical removal, are used to determine the calibrated condition of the instrument. This is an expensive and time consuming activity; however it is essential to the process plant and preventative maintenance activities (Coble *et al.*, 2012). The unit under test (UUT) is compared against a documented tracible flow reference unit. The deviation between the UUT and the reference unit indicates how well the instrument is reading and if there needs to be an adjustment (Camnasio and Orsi, 2011). If a flow instrument has been adjusted and/or repaired the calibration results before and after adjustment need to be reported and available (International Organization for Standardization, 2006).

Documentation and recording are an essential part of preventative maintenance and specifically calibration activities. Without the documentation there is seldom a way to track and portray traceability as well as feedback this information into the system (Notice, 2017).

2.3.6 Summary

Each process is just as important as the next and must occur in the life cycle of the flow instrument.

A review of the literature demonstrated that there are different types of PM activities on flow instrumentation. These preventative maintenance activities include visual inspection, cleaning, functionality test, verification as well as calibration of flow meters. These preventative maintenance activities are described in a summary table, Table 1, below.

Table 1: Preventative measuring instrumentation maintenance activities

#	Preventative activity	Summary description of activity	Article referenced
1	Visual inspection	Visual inspection can be conducted by looking at the instrument to find any visible faults or errors.	Khan and Haddara, 2003; Grieb, Linzenkirchner and Theilmann, 2005; Wang *et al.*, 2010; Kuboki and Takata, 2019
2	Cleaning of instrument	Cleaning of the instrument removes any deposit layer in the instrument's sensor or the transmitter. There are two methods of cleaning, one physical and the other automatic.	Morison and Thorpe, 2002; Wilson, 2005; Mostafa, Dumrak and Soltan, 2015
3	Functionality Test	The functionality test is conducted by checking how the instrument is operating in the field. This functional test ensures that the flow meter meets process plant output requirements	Alhamad, Alardhi and Almazrouee, 2015; Toteva, Slavov and Vasileva, 2017; Nyemba and Mbohwa, 2018
4	Verification	A verification is performed by checking that all the internal electronics as well as the sensor are functioning correctly. This is done by analyzing the sensor to see if it is measuring and often simulating the transmitter of the instrument. By either using an external tool or another flow meter.	Roughan and Doorhy, 2009; Hashemian, 2010; Natalinova, Ilina and Frantcuzskaia, 2016; Toteva, Slavov and Vasileva, 2017

Table 2: Preventative measuring instrumentation maintenance activities

5	Calibration	Calibration is comparing the unit under test (UUT) against a reference unit. Here the unit under test (UUT) is often taken out of the process and becomes an expensive, time-consuming yet essential activity. The deviation between the reference and UUT will indicate how well the instrument is performing and if there needs to be an adjustment.	Camnasio and Orsi, 2011; Lei *et al.*, 2011; Coble *et al.*, 2012; Notice, 2017; Toteva, Slavov and Vasileva, 2017

2.3.7 Management of technical personnel conducting preventative maintenance activities on flow meters

The preventative maintenance activities as stated above can ensure the sustainability of flow meters and production continuation on process plants. Having the engagement of technical personnel knowing how to perform these activities helps to achieve suitable flow instrumentation preventative maintenance.

However, there are also some drawbacks such as a need for experts and software for analysing complex calculations (Matttsson, 2002). This can lead to increase in cost as well as complexities in data management. Environmental settings can influence the methodology of preventative maintenance planning (Basri, Tiek and Kamaruddin, 2014). Grouping procedures on systems and components can be proposed for reliable data and better input. On literature review it was found that all the above-mentioned methodologies are varied and complex and there is a need to design a simple and effective system to manage technical personnel conducting preventative maintenance. In order to do this the relevant knowledgeable technical staff (e.g. engineering managers) that are adequately aware of the effects of not conducting the above-mentioned preventative maintenance are necessary (Matttsson, 2002).

2.4 Impact of not conducting preventative maintenance activities on flow meters

Process plants and industry systems depend upon maintenance activities (Swanson, 2001). However, if no preventative maintenance occurs, the process plant will eventually not be profitable or could stop producing. This is likely to occur as a result of the time spent on reactive breakdowns becoming more than the running time of the process plant (Kolte and Dabade, 2017; Toteva, Slavov and Vasileva, 2017).

The impact of not performing each type of preventative maintenance activity on flow meters is further described below.

2.4.1 The impact of not performing visual Inspection

If a process plant does not have a visual inspection system, even online through a controller, it can increase the breakdown time by up to 5%, as the root cause of the problem is not predicted and managed upfront (Fornaro, Magro and Pinceti, 2004). No corrective maintenance can occur early and in line with production routines. This in turn also implies that a repair of a flow meter for example cannot occur while a certain section of the plant is running (Grieb, Linzenkirchner and Theilmann, 2005)

If no visual inspection is performed on process plants, this could lead to high reactive maintenance costs, as faults or problems will not be picked up until this process measurement point becomes a used essential (Kuboki and Takata, 2019). This will then lead to higher breakdown load and an increase in reactive maintenance (Grieb, Linzenkirchner and Theilmann, 2005)

When there are no visual inspections, visible process product leaks on a plant cannot be detected. This will inevitably cause financial losses. Visual inspection of instrumentation, including flow meters, helps to detect, report and reduce this (Altendorf *et al.*, 2006; Moran, 2015). Moran (2015) states that if no visual inspection takes place, even though in-line monitoring by fixed sensors is completed on the plant, there can be financial losses of up to 25% (Moran, 2015). If no visual inspection is conducted on process plants, this can increase the risk of obvious malfunctions such as dents, lose bolts, or even flow meter electronics exposed to the elements which can induce breakdowns on the plant (Fornaro, Magro and Pinceti, 2004).

2.4.2 The impact of not cleaning flow meters

When an instrument is not regularly cleaned, thin film or substantial build up can occur. If this build up is not cleaned, it can affect the measuring accuracy of the instrument (Wilson, 2005). In addition to this extra time can be added to reactive events as access to the device components becomes problematic (Cheng, Chen and Guo, 2007).

Clear visual inspections and function checks can also be performed well on the instrument if it is cleaned timeously (Wilson, 2005; Kuboki and Takata, 2019).

2.4.3 The impact of incomplete functional tests

When functional testing is not occurring on a process plant as part of PM activities, parameters of flow meters can be affected. The outputs from these parameters are not checked and changed and therefore flow measurements could be incorrect (Toteva, Slavov and Vasileva, 2017).

If no functional test is performed, flow meters will not meet output requirements of process plants and misaligned values outputs will occur (Toteva, Slavov and Vasileva, 2017; García-Berrocal et al., 2019)

A prime example of this is in the oil and gas (hydrocarbon) industry. In this industry particularly, the product is charged at a high cost. If the system on the programmable logic controllers (PLC's) and the flow meters output values are not aligned this can cause a misassignment in values. While the flow meter may be reading 5 l/h the PLC may be reading 2 l/h for example. This difference if not tested and checked can cause a loss in profit, due to this misalignment in output to input values (García-Berrocal et al., 2019).

2.4.4 The impact of not performing verification activities

If there is no verification activity completed on a flow measuring instruments after an extended period, correct values to the control room are compromised (Roughan and Doorhy, 2009; Toteva, Slavov and Vasileva, 2017). This also means the internal algorithm in the flow meter is not verified to ensure it works according to specification, which introduces an amount of uncertainty (Natalinova, Ilina and Frantcuzskaia, 2016; Toteva, Slavov and Vasileva, 2017).

Ensuring verification activities allows confidence in what the flow meter is measuring and working according to its internal or external reference points. If this does not take place the process line often has to be stopped in order to confirm this, which results in a loss of production. This will mean reactive maintenance will occur, causing down time to production and a loss of profit (Toteva, Slavov and Vasileva, 2017).

2.4.5 The impact of not performing calibration activities

As seen in the above section, Verification and Functionality Test, it is imperative to perform these activities in addition to calibrations as a preventative maintenance. If there are no calibrations performed on flow measuring instruments this could introduce a range, of sometimes difficult to detect problems (Camnasio and Orsi, 2011; Lei et al., 2011).

Without calibration the flow meter relies only on the internal algorithm to give a correct value, even though this value can be verified, this algorithm contains uncertainty. If no calibration takes place the flow meter will produce flow readings with greater than acceptable inaccuracy. A non-calibrated flow meter in a process with different piping configurations, pipe frictions, product temperatures and other factors adds to the uncertainty of the flow measurement (Coble et al., 2012; Baker, 2016).

This certainty of measurement is a legal requirement in certain industries and processes and if there is no certification appointed to this activity this could mean a monitory fine or the shutdown of a plant (South African National Standards. 1st edn, 2001; ISO 9001:2015(en), Quality management systems — Requirements, 2015). If calibration is required, or uncertainty is present in the flow measurement, the process plant will need to be stopped and calibration will take place. This means a loss in production and the cause of down time if not planned correctly (McMillan and Vegas, 2019).

2.4.6 Summary

Preventative maintenance activities on flow instruments are carried out to avoid difficulties arising, to control errors and to guarantee equipment in functioning efficiently and effectively. A preventative maintenance program will make the plant and flow instruments more dependable.

As seen in the above however, if no preventative maintenance activities occur these errors and guarantees start to fall away. This can be seen in summary in Table 3. In Table 3, these activities are represented on the impact to the plant if such preventative maintenance activities do not occur.

Table 3: Impact of not conducting preventative maintenance activities

#	Preventative Activity	Summary of impact if no preventative maintenance activities occur	Article Referenced
1	Visual inspection	If there are no visual inspections occurring on the plant, then no upfront PM can occur which adds to an increase in reactive maintenance events as well as a higher maintenance cost. Obvious dents, malfunctions and even exposed components of flow meters will not be picked up and actioned if no visual inspections occur.	Fornaro, Magro and Pinceti, 2004; Grieb, Linzenkirchner and Theilmann, 2005; Altendorf *et al.*, 2006; Moran, 2015; Kuboki and Takata, 2019
2	Cleaning of instrument	If there is no cleaning of a flow instrument build-up can occur which can induce measurement inaccuracies. In addition to this, clear visual inspections and function checks cannot be performed well on the instrument if it is not clean. This will increase reactive maintenance time and costs.	Wilson, 2005; Cheng, Chen and Guo, 2007; Kuboki and Takata, 2019
3	Functionality Test	When no functional test is performed, flow meters will not meet process plants output requirements and misaligned value outputs will occur. This can cause inaccuracies in production.	Toteva, Slavov and Vasileva, 2017; García-Berrocal *et al.*, 2019

Table 4: Impact of not conducting preventative maintenance activities

4	Verification	If no verification takes places this means the internal algorithm in the flow meter is not verified to ensure it works according to specification, which introduces an amount of uncertainty.	Roughan and Doorhy, 2009; Natalinova, Ilina and Frantcuzskaia, 2016; Toteva, Slavov and Vasileva, 2017
5	Calibration	If no calibration on the flow meter takes place. The flow meter relies only on the internal algorithm to give a correct value, even though this value can be verified, this algorithm contains uncertainty. If no calibration takes place the flow meter will produce flow readings with greater than acceptable inaccuracy.	Guth, 1989; Camnasio and Orsi, 2011; Lei *et al.*, 2011; Coble *et al.*, 2012; Baker, 2016; McMillan and Vegas, 2019

2.5 The perceived value of preventative maintenance

Flow measurement is an important factor for any process plant that desires to guarantee specified and excellent results. For that reason, understanding attitudes regarding the value of maintenance on such instruments is important (Sharma, Debnath and Musa, 2018).

When technical personnel make measurements, they normally assume that some precise and real impact on the plant exists based on how they define what is measured, and according to the stability and precision of the measuring instrument (Nakaya and Yoshizumi, 2019). They may not ever recognize the real value behind, and the effort required to obtain, this exact measurement. As they make measurements by diverse methods, or even when building multiple measurements using a similar technique, they may acquire faintly different outcomes (Lei *et al.*, 2011). Götze *et al* (2017) suggests that in the life cycle of an instrument if the measurement is not important, then the maintenance and the care of the instrument will also not be (Götze *et al.*, 2017). Similarly, according to Emmanuel (2010), technical responsible personnel indicate that maintenance is not important on a device that does not bring direct value to them, the process plant or the operation. If a device does not have a valuable reading or an understood reading, then the maintenance and upkeep of such a device is perceived as unimportant (Emmanuel, 2010).

Gasskov (1992) indicated that one of the major perceived causes of poor maintenance in some countries of the SADC region has been due to so called "crises government", in which there are no incentives provided for developing creative maintenance solutions. He goes onto suggest that governments also have a negative attitude towards maintenance (Gasskov, 1992). Reiman and Oedewald (2004) also surveyed the perceptions of technical personnel towards measuring maintenance and maintenance core tasks. The authors revealed that due to high financial stress levels on individuals working in poorly paid industries, the value of proper maintenance was not realized. This could be due to the fact that if people view themselves as poorly looked after by a company they will not look after the company, including the company's instruments. They go on to say that if the technician's safety is compromised and there are unsafe working environments, maintenance is not viewed as important at all (Reiman and Oedewald, 2004). As unsafe working conditions increase on the plant, the value of preventative maintenance across the whole plant decreases (Taylor, 2000).

Enofe (2009) writes that technical personnel conducting maintenance in developing countries, such as in the SADC region, perform this maintenance poorly. This is due to lack of training which directly contributes to the viewed importance of maintenance. The author also suggests that the conflict with cultural values and inappropriate attitude towards maintenance is a delicate topic and creating an attitude that will be favourable to maintenance would not be easy (Enofe, 2009).

Visser and Moeko (2013) suggest in the Southern African power industry that preventative maintenance is not a priority and although completed, seldom conducted the way it should. They also go on to mention that less than half of the utilities are compliant in terms of regular maintenance work, of which PM falls a part of (Moeko and Visser, 2013).

2.6 Conclusion

In conclusion it is imperative to conduct preventative maintenance activities on flow meters. Different mathematical systems determine when each activity should take place (Bokrantz *et al.*, 2019). As seen from the above literature review preventative maintenance activities ensures a cost effective, safe and healthy process plant. However, if no maintenance is conducted on the flow instrument, the instrument will not last in its original state, and breakdowns with added downtime will occur on the plant.

Chapter 3

3 Research methodology

This chapter will discuss the methodology which was employed to collect and analyse the data to answer the research questions listed in chapter 1. This will be in combination with chapter 2, the literature review which was completed in order to gain valuable insight into the research problem. This literature review established what the expected flow instrumentation preventative maintenance is, and the consequence of not conducting such maintenance. This chapter provides a description of the data collection method and the data analysis methodology.

3.1 Research methodology

The methodology indicated how the research will systematically solve the research question in a structured manner. It was a continuous process of assessing if the research problem could be solved. There is a systematic method as portrayed in the figure below, Figure 1. A survey in the form of a questionnaire was developed to ascertain the frequency of conducting preventative flow instrument maintenance as well as associated activities. It also looked at the impact that the lack of these preventative maintenance activities could have on the plant. In addition to this, certain questions were designed to ascertain the perceived importance of conducting preventative maintenance in the SADC region. As seen in Figure 1, the definition of the problem is defined and then the design is portrayed. Once this has been completed the data is collected and analysed and finally the results are presented.

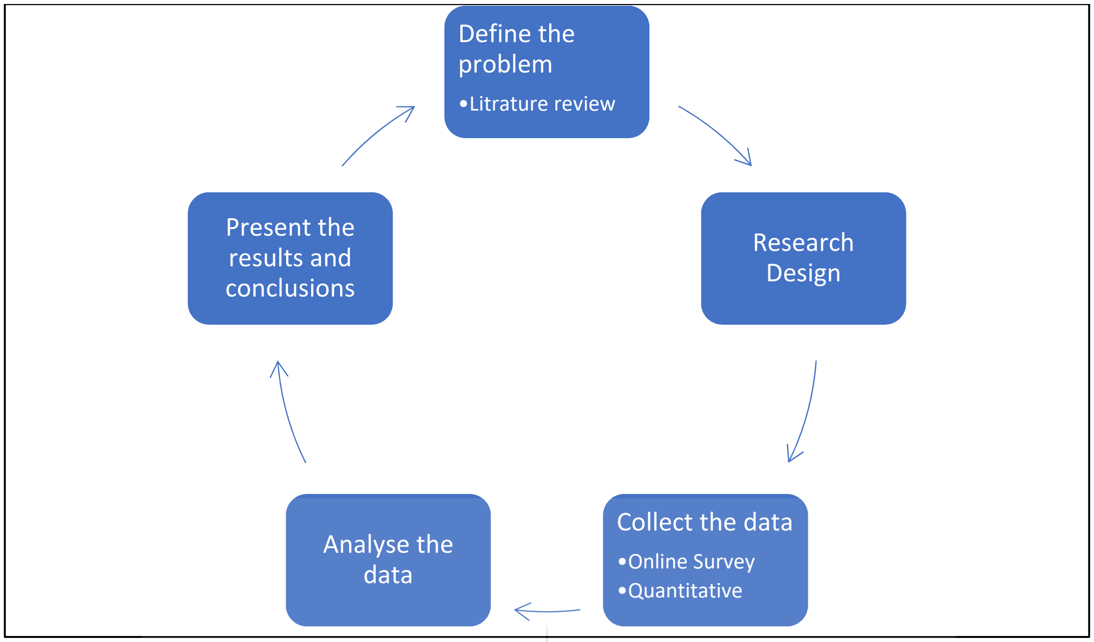

Figure 1: Basic steps to research (Rose, Spinks and Canhoto, 2014)

In Chapter 2, the Literature Review is where the problem is defined, and interesting insights are realized. As the steps are followed the research design is also presented based on the findings from literature. This research design can be seen in the section below. The final step is to present the results and conclusions of the research which could then lead into new research problems, which is presented in possible future research.

What is also important in the steps of research is the collection and analysis of the data. In the below figure, Figure 2, will give an overview of the methodology, the data collection style as well as which technical personnel will be targeted. The methodology used was a survey, through the snowballing sampling process. This survey was 14 questions with select response options. The figure also describes how the data will be analysed as well as how this data will be presented.

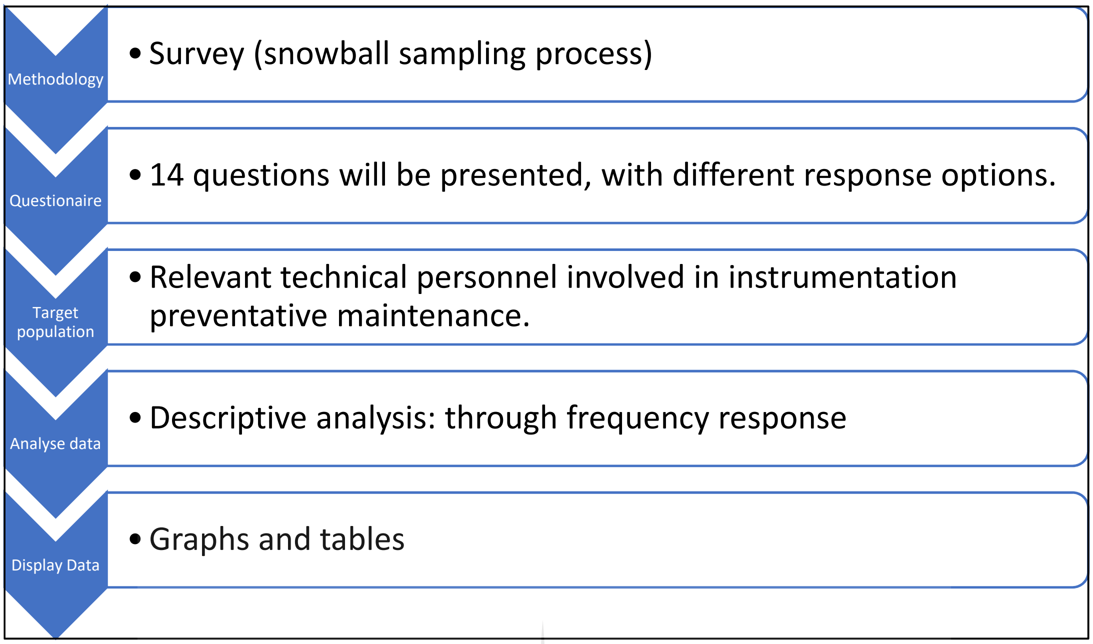

Figure 2: Research Methods (Dawson, 2013)

3.2 Research design

The research design encompasses all the steps followed in each chapter as well as the plan to assist in answering the relevant questions. The main objectives were to portray a quantitative description of what preventative maintenance is in terms of flow instrumentation, as well as the consequences of not conducting such maintenance. This activity requirement crossed multiple roles and job functions on a process plant. The research design also ensured that the recommended methodologies described in the literature review were being used appropriately.

The target population was technical personnel responsible for the relevant preventative maintenance activities or instrumentation on their respective plants. Snowball sampling, with targeted respondent driven sampling (Marpsat and Razafindratsima, 2010; Vogt *et al.*, 2014), was used for data collection. This sampling process involved contacting a small group of people and using these contacts to establish new contacts with others (Marpsat and Razafindratsima, 2010).

There were two different approaches that were adhered to, to find the correct respondents for the survey. This ensured that the methodology was effective in reaching the appropriate respondents. These two methods are as below.

- A list of individuals was already known by the researcher. These individual relationships were built over time through working in the industry, various informative knowledge seminars as well as campus classes and through social networking such as industry talks. These individuals were contacted directly and asked to complete the survey. They were also asked to distribute the survey link to their respective network and colleagues.
- Relationships were also formed between the researcher and respective external instrumentation sales engineers in the appropriate sectors. These engineers also have a network of clients working in the appropriate industry often responsible for instrumentation maintenance. This survey was sent to the sales engineers to distribute to their network.

A survey is a data collecting process designed systematically to extract responses from respondents for the purpose of collecting the required data, which will provide insight into the nature of the problem being studied (Fowler, 2012; Ornstein, 2014). After careful consideration of the disadvantages and advantages of various survey types it was decided that an internet survey would work the best (Vogt *et al.*, 2014). This meant that individuals could also pass on an appropriate link and it could be filled in.

3.3 Data collection

The primary source of data collection was by means of a questionnaire. The questionnaire will be placed online and sent to a network who may also send it to their respective colleagues. The survey was designed to target technical staff who are responsible for instrumentation or maintenance on their plants. The survey was designed to achieve the research objectives.

The questionnaire was short and focused on the research question. Each question had a limited set of answer choices. This can be seen in appendix A.

3.3.1 Questionnaire design

Developing the questionnaire aimed to operationalize the research questions and process. The design of the questionnaire was presented as follows:

- Some background questions were asked in order to determine demographic information. This provided an insight in determining what the respective person does, as well as which type of process plant they may work on and in which SADC region. It also clarified if this individual is accountable for instrumentation on the process plant.

- The second section of questions asked about the amount of flow instrumentation that existed on the plant and if there was a system that determined when a flow meter required maintenance.
- Adequate questions were then asked which will address the main research goal. These questions relate to conducting of preventative maintenance and the impact of not conducting such maintenance. This accounted for most of the data collected.

The survey was constructed by analysing the research questions posed in chapter 1. Each of these questions had a specific outcome required and the research that related to it. This can be seen in the below table, Table 5.

Table 5: Design of questions related to literature review and research questions

Research Question (section 1.3)	Literature review (Chapter 2)	Questions asked (Appendix A)
RQ1: What are the preventative maintenance activity practices required on a measuring instrument on a plant?	2.3 Table 1	Questions: 7; 8.1; 9.1; 10.1; 11.1; 12.1
RQ2: What is the impact on the measurement performed by the measuring instrument should preventative maintenance activities not take place on the plant?	2.4 Table 3	Questions: 8.2; 9.2; 10.2; 11.2; 12.2
RQ3: Is preventative flow instrumentation maintenance perceived as important to the technical personnel?	2.5	Question: 5 and 7 as well as extrapolation from question 8 to 12

The questions were designed to be easy at the beginning and then gradually develop into more complex technical questions. The online questionnaire also ended with at least one easy question in order to keep the respondents attention (Fink, 2003). Response formats were standardized to enable the researcher to analyse the results easily (Fink, 2003). The questionnaire was also kept short so that a full focus and attention could be used to answer all the questions. Respondents are found to be quickly uninterested by long and complex instructions for answering questions, including long explanations around each question (Ronald and Blair, 2005). The following guidelines were used to design the questionnaire (Toepoel, 2008; Ornstein, 2014):

- Pre-coding of response categories to allow for easier response
- A maximum of 20 minutes to answer all the questions
- Simple instructions
- Avoidance of jargon and complex words as far as possible
- Explanation of definitions where required

If participants had to scroll down onto the next page the chances of them not completing all the questions become higher (Toepoel, 2008). A considered effort was made to place as many questions as comfortably and visibly possible on one screen.

The internet survey was chosen due to its advantage of being a predictive and efficient way of collecting data. Some of the advantages include (Ronald and Blair, 2005):

- Cost effective
- It can be distributed over a larger area easily
- Data collection is quicker
- It is the easiest and most convenient for the respondents

There are some disadvantages that could have been encountered by using an online survey. Firstly, participants who do not have the internet (or stable internet) will not be able to answer the questions posed. Secondly, the language barrier in the DRC, Mozambique etc. countries. There could also be a bias created as the survey may only reach certain peer individuals and not the broad network as intended. The final foreseen disadvantage is that any person who has access to the internet and the link will be able to answer the survey, even if they do not work in the plant. This could result in inaccurate data (Fink, 2003).

3.3.2 Pre-testing

Once the questionnaire was developed, it was tested to ensure that it worked correctly, and it could go live (Fowler, 2012). Once the online questionnaire was completed various pre-tests were conducted. These tests included the survey duration, a pilot test as well as a confirmation of the online link.

3.3.3 Implementation of survey

The survey was designed and opened on google forms. The data collection was facilitated by the platform on which the survey was designed. The survey link was sent via email to all the relevant participants and colleagues where they could pass this email on. Information was provided to all participants that the questionnaire was sent to. This information was an introduction to the purpose of the research and some background information on the research. Contact details were also provided to the respondents should they require any additional information or understanding of the questions posed.

The selection of participants was designated in order to meet the required sampling plan. The respondents were any technical personal that were responsible for maintenance activities on their respective plants. This also included managers who were responsible for maintenance, specifically looking at instrumentation maintenance.

Some participants were spoken to directly, the research was explained in brief and a link was sent on email. The survey link and description were also placed on LinkedIn so the researcher's network could access it and complete it.

3.4 Data analysis

The analysis phase of the survey was a complex process where the researcher had to analyse the collected data and present the findings. This followed the steps shown in Figure 3.

Once the data was received from the questionnaire, the processes began with formatting the data by entry into a computer aided program (Excel). The data then had to be cleaned up and formatted to make sense (Rose, Spinks and Canhoto, 2014). The data was then analysed by checking each variable and answer to each question separately.

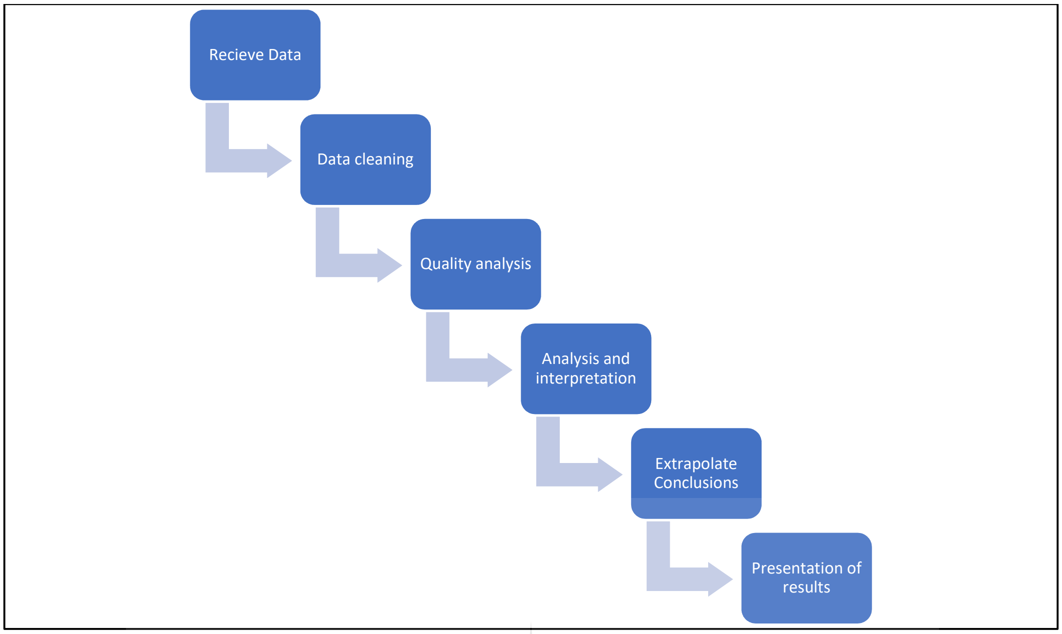

Figure 3: Data analysis steps (Rose, Spinks and Canhoto, 2014)

The next step involved interpretation of the analysis in order to make conclusions arising from it. The last step is to present the findings in the best possible way.

3.5 Conclusion

Various literature information was reviewed and presented in chapter 2 to create a foundation for this research paper. To enable the researcher to answer all the questions presented in chapter 1, a literature review was conducted. A questionnaire was then developed and presented to individuals involved in the process plant industry. These questions were answered and analysed. All data obtained was presented and analysed according to the plan stipulated in chapter 3. A comprehensive data collection and analysis on the research topic is presented in chapter 4, with the discussion of the results in chapter 5.

Chapter 4

4 Data collection and analysis

The purpose of this chapter is to present the data obtained from the survey process. The results are shown for the questionnaire and then analysed.

In the SADC region there is no clear indication of how many plants fall under the four sectors asked in the questionnaire. There is also no information on how many technical personnel are accountable for these instruments per plant. The researcher acknowledges that the required response rate is very difficult to estimate, however, the 101 responses will give a relative description of what is happening.

The data presented is divided into two sections, descriptive analysis where the raw data is presented and data analysis, where this data is analysed by using cross tabulation. The descriptive analysis section is divided into two sub-sections. The first consist of general data about the plant as well as the technical person filling out the survey. The second sub-section is more technical and focuses on preventative maintenance activities, if the activities were being completed and the perceived consequence of not conducting the activities. The final section, data analysis, interpreted the descriptive data, to see if preventative maintenance activities were really perceived as important.

4.1 Descriptive analysis

The results of the questionnaire are presented in the following sections of this chapter. The first section looks at the background information of both the individual answering the questionnaire as well as information about their respective plant. In the second section, it portrays the preventative maintenance of flow instrumentation activities on respondents' plants.

4.1.1 Respondents' background

Some questions were targeted on details regarding the respondent's role on the process plant.

4.1.1.1 Respondents role

The respondents were asked to indicate their role on the plant, choosing from a list of presented options.

The data is summarized, in Figure 4. In this case 48% of respondents were instrumentation technicians, or part of a maintenance team on the plant. One quarter (25%) came from automation engineering and the remaining 27% of people were artisans or in engineering maintenance management.

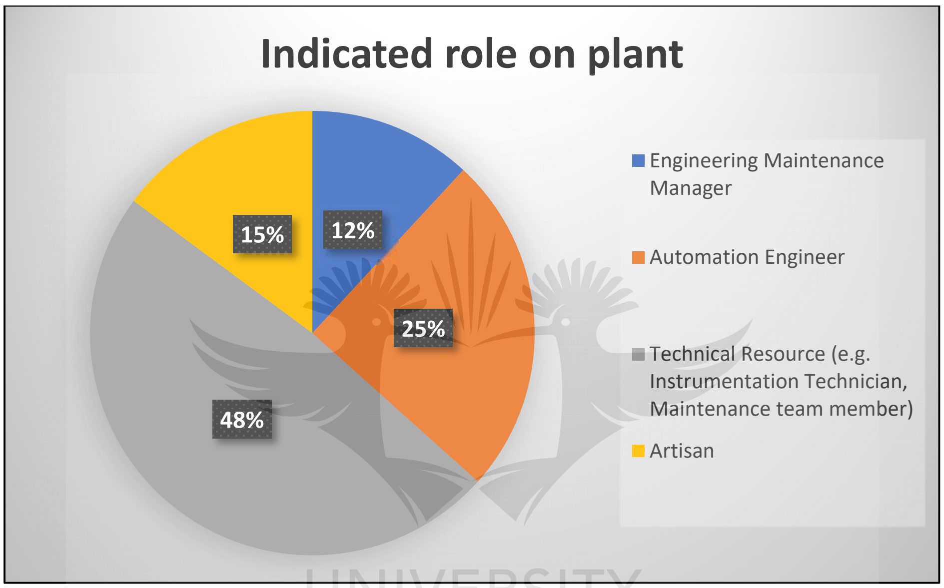

Figure 4: Different technical personnel roles on plant according to survey data

4.1.1.2 Role responsible for instrumentation

Respondents were asked to indicate if their role was responsible for plant instrumentation or not. This was a yes or no question. The aim was to determine if the persons answering were responsible for flow meter instrumentation and their maintenance.

All participants indicated that their role was responsible for the instrumentation on their respective plants. With this feedback, it is safe to assume that every participant who filled out this survey had a role to play in maintaining a flow instrument. This role could be deducing a schedule for conducting the maintenance or performing the actual maintenance.

4.1.2 Plant background

Some questions were targeted on details regarding the plant.

4.1.2.1 Location of plant

The location of the plant was requested to establish where it is situated in the SADC region. As seen in Appendix A, different countries were available from the questionnaire drop down selection; the list of countries is presented in Figure 5.

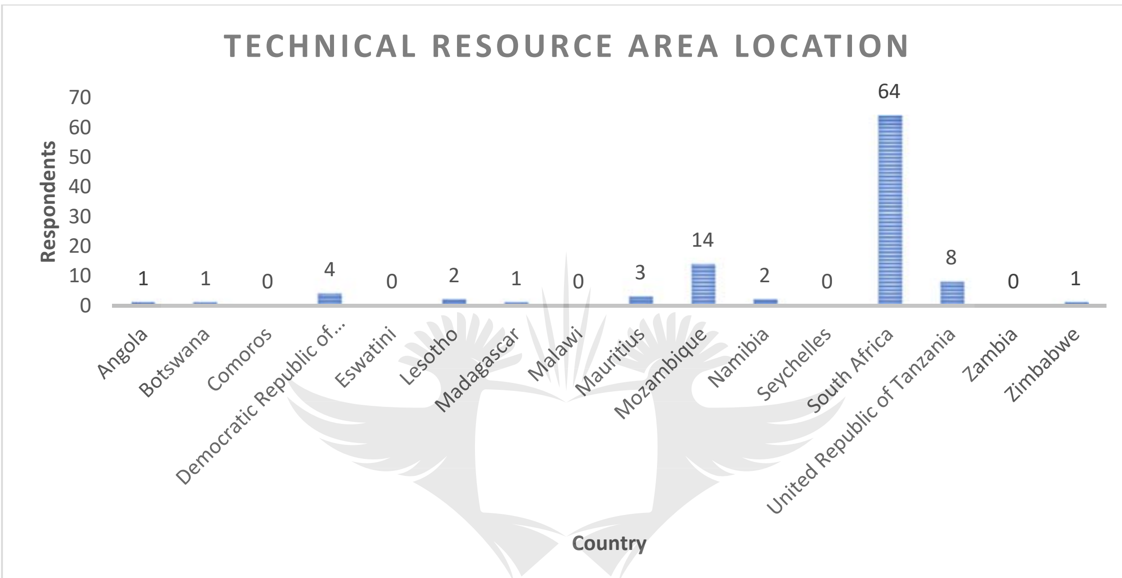

Figure 5: Country where plant is located according to survey data

It can be seen that 64 technical personnel respondents were in South Africa. Of note is that 14 respondents came from Mozambique and 8 of the respondents were from Tanzania. These three countries made up 85% of the respondents while the remaining 15% of the respondents worked on plants in Angola, Botswana, DRC, Lesotho, Madagascar, Mauritius, Namibia and Zimbabwe.

4.1.2.2 Type of process plant

The type of plant was asked, to establish the sector the flow instrument was operating in. The type of process plant will establish how regulated and strict the requirements for maintenance are and how these activities should take place. The results can be seen in Figure 6.

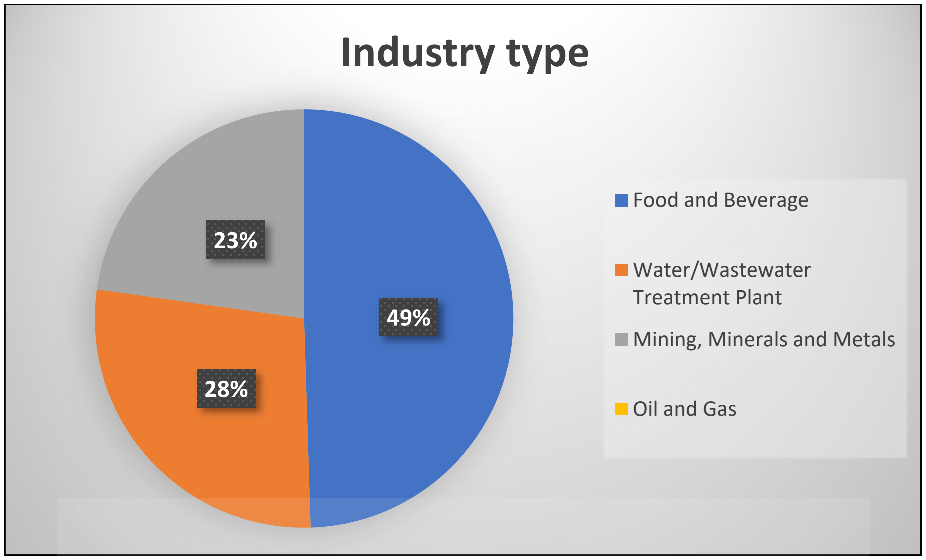

Figure 6: Type of industry according to survey data

Most of the participants answered that they came from the Food and Beverage industry, with just under 50%. The other sectors were Water/Wastewater treatment plants and finally Mining, Minerals and Metals. It is noticeable that none of the participants came from the Oil and Gas industry. It is suspected due to the current oil and gas crisis that no participants could answer, even though the survey was sent to them (Coleman, 2020).

4.1.2.3 Age of plant

This question established the age of the plant. This would indicate what was the expected reactive maintenance as well as the amount of preventative maintenance that could have been taking place.

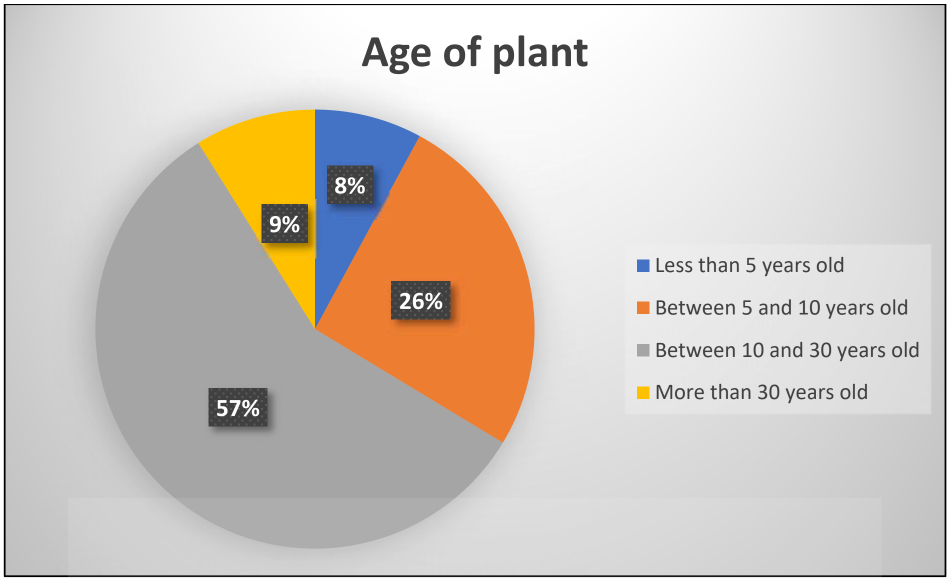

Figure 7: Age of Plant according to survey data

57% of the participants indicated that their plant was between 10 and 30 years old, and 26% of the participants reported that their plant was between 5 and 10 years old (See Figure 7). The last quarter of participants indicated that their plants were either younger than 5 years or older than 30 years. As seen from the survey results, 66% of respondents indicated that their plant was more than 10 years old and this, according to Moran (2015), is considered an older process plant (Moran, 2015). As mentioned in chapter 2, Interval timing of preventative maintenance, the older the plant or the instrument the higher the change in frequency of preventative maintenance (Duarte, Craveiro and Trigo, 2006).

4.1.2.4 Amount of flow instrumentation

This question established the number of flow meters that were present on the plant. As seen in Figure 8, most of the plants (47%) had between 500 and 1000 flow instruments. The survey also indicated that 11% of respondents did not know how many flow instruments were located on their plant, despite the fact that 100% of respondents indicated that they were responsible for flow meters.

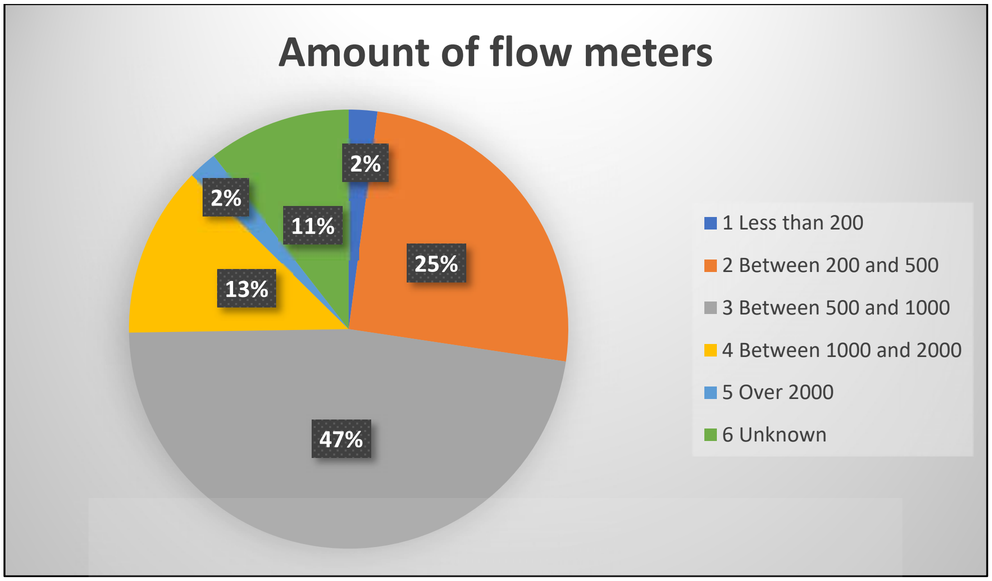

Figure 8: Amount of flow meters on respondents' plant according to survey data

4.1.3 Preventative maintenance activities

These questions enquired about two different aspects. The first, and probably one of the most important questions (question 7), was if there was a system to indicate when certain preventative maintenance needed to be completed. The questions that followed also asked if visual inspection, cleaning, functional tests, verifications as well as calibrations were being performed. In addition to this, the survey asked the participant to indicate if no activity was performed on a flow meter, how it affected the plant. The last question asked whether, if reactive maintenance did occur (flow meter breakdown), the technical personnel would replace the whole unit or repair it.

4.1.3.1 Preventative maintenance system

This question asked if there was a system that indicated when a Preventative maintenance activity needed to take place. As seen in chapter 2, Validation techniques for preventative maintenance, it is essential to have a system that indicates when preventative maintenance needs to take place. Figure 9 indicates that just under half of respondents (47%) do have a system to indicate when various preventative maintenance activities need to occur. However, more than half (53%) of technical respondents do not have a system that indicates this, as they either are not familiar with preventative maintenance activities (26%) or they indicated that they do not have a system (27%).

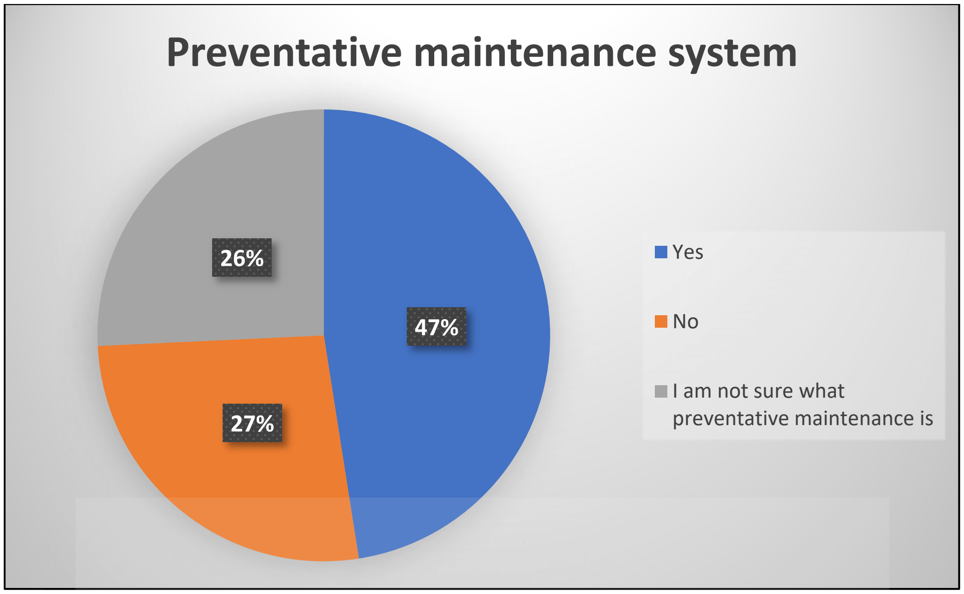

Figure 9: Preventative maintenance system on plant according to survey data

4.1.3.2 Descriptive analysis of the five different preventative Maintenance activities

As seen in the above section, and mentioned in chapter 2, Preventative maintenance activities on flow instruments, it is important to be conducting each of the preventative maintenance activities. Provided one completes these activities in a preventable way, on a flow meter in the plant, this will increase the life cycle. Technical personnel can also complete these maintenance activities reactively (when the instrument fails). The following table, Table 6, includes the responses given to each preventative maintenance activity as well as a total of preventative maintenance. The table also presents how many of these activities occur as a reactive event. Each preventative maintenance activity is discussed in the following sections.

Table 6: Frequency of preventative maintenance according to survey data

	Frequency of Preventative Maintenance	Visual inspections		Cleaning		Functional checks		Verifications		Calibrations	
		N	Percentage	N	Percentage	N	Percentage	N	Percentage	N	Percentage
Proactive	Once a day	2	2%	2	2%	0	0%	0	0%	0	0%
	About once a week	5	5%	13	13%	7	7%	0	0%	0	0%
	About once a month	15	15%	10	10%	8	8%	7	7%	2	2%
	About once a quarter	10	10%	8	8%	16	16%	10	10%	7	7%
	About once a year	17	17%	18	18%	16	16%	29	29%	31	31%
	About once every three years	3	3%	6	6%	4	4%	7	7%	14	14%
	Once every five years or more	0	0%	1	1%	4	4%	2	2%	3	3%
	Proactive maintenance total		52%		58%		55%		55%		57%
Reactive	When the instrument fails	49	48%	43	42%	46	45%	46	45%	44	43%

Besides the above table, Table 6, the impact of each preventative maintenance activity is also discussed. Technical personnel were asked for their perceived consequence on the plant should a flow meter fail. The table, Table 7, includes these responses given if no preventative maintenance activity occurs. The table then summarises how many participants indicated that there will be an impact on their plant should no PM occur. The table also indicates the number of participants that indicated that there is no impact on their plant or that they do not perform preventative maintenance on the plant. This table is also part of the sub-sections below.

Table 7 : Impact of preventative maintenance on the plant according to survey data

	Impact of Preventative Maintenance	Visual inspections		Cleaning		Functional Checks		Verifications		Calibrations	
		N	Percentage	N	Percentage	N	Percentage	N	Percentage	N	Percentage
Impact	Less than 1% of the flow meters breakdown and cause downtime	19	19%	17	17%	14	14%	15	15%	18	18%
	Between 1% and 3% of the flow meters breakdown and cause downtime	13	13%	20	20%	30	29%	27	26%	18	18%
	Between 3% and 5% of the flow meters breakdown and cause downtime	16	16%	12	12%	13	13%	13	13%	26	25%
	More than 5% of the flow meters breakdown and cause downtime	8	8%	15	15%	8	8%	9	9%	13	13%
	Impact subtotal		56%		64%		64%		63%		74%
	No impact	10	10%	7	7%	9	9%	12	12%	4	4%
	I do not perform this maintenance on my plant	35	34%	30	29%	27	27%	25	25%	22	22%

4.1.3.2.1 Visual inspection

In this question (question 8), visual inspection was explained in a few sentences. The participant then had to indicate if visual inspections were being performed on flow meters (question 8.1). The results are presented in the "Visual inspections" column in Table 6. The participants indicated that visual inspection was being completed as a preventative maintenance such as once a year, once a month etc. In this case, 52% of participants indicated that they do conduct visual preventative maintenance, with most of them completing this activity once a year. However, what is significant to note, is that almost half (48%) of participants only conduct visual inspection as a reactive (when instrument fails) activity.

The next part of the question (question 8.2) was the consequence of not conducting visual inspection of the flow meters as perceived by participants, presented in Table 7. This question looked at the impact of not conducting preventative visual inspections according to the respondent. What does stand out from the data is that 10% of participants indicated that there is no impact if no visual inspection takes place. On the other hand, it is noteworthy that 34% of participants state that they do not perform visual inspection at all. While this is seen, it is also realized that 56% of participants in total indicated that there will be an impact on their plant if no visual preventative maintenance activity is completed.

4.1.3.2.2 Cleaning

In this question (question 9), cleaning of the flow meter was explained in a few sentences so the participant could answer the question to their best understanding.

In the first part of the question (question 9.1) the participant then had to indicate if cleaning was performed on flow meters on the plant. The result of this can be seen in the "Cleaning" column in Table 6. In this data, 42% of participants indicated that they only clean flow meters when the instrument fails, as a reactive event. The other 58% of participants conduct cleaning as a preventative maintenance activity (once a day, month, year etc.). Most of the technical personnel indicated that they conducted cleaning once a year, which was followed by those that clean once a week.

The next part of the question (question 9.2) the participants were questioned on the perceived consequence of not cleaning flow meters. This is presented in the "Cleaning" column in Table 7. Here it is observed that 64% (total that indicated that there will be an impact such as more than 5% down time) of participants indicated there will be an impact. In this column in Table 7, it is also seen that 7% of participants indicated that there will be no impact if no cleaning is completed. The last 29% of participants indicated that they do not perform cleaning on their respective plants at all.

4.1.3.2.3 Functional checks

In this question (question 10), an explanation of a functional check was given. The participant then had to indicate if functional checks were being performed on flow meters on the plant as well as the impact of conducting such maintenance.

The first part (question 10.1) data indicated, as seen in Table 6, that 45% of technical personnel only conduct functional checks when the instrument fails. However, 55% of participants indicated that they do conduct preventative functional check maintenance, whether it be once a year or once every three years or more.

The next part of the question (question 10.2) asked the participants about the impact of functional checks on the plant. As seen in Table 7, 27% of participants indicated that they do not perform functional checks while 9% indicated that there would be no impact on their plant if functional checks were not conducted. The remaining 64% of participants indicated that there will be an impact on their respective plants if no Preventative maintenance is conducted.

4.1.3.2.4 Verifications

In the second last preventative activity, verifications were discussed and, in this question, (question 11), the basics of verification activities were explained.

The respondent then had to indicate if verifications were being performed on flow meters on the plant (question 11.1). These results are presented in the "verifications" column in Table 6. Here it is seen that 45% of participants indicated that instruments are only verified when they fail. The other 55% of participants indicated that they completed verifications as a preventative maintenance (Once a year, once a quarter etc.). The most participants indicated that they completed verifications once a year and 10% indicated that they completed verifications as a preventative activity once a quarter.

The next part of the question (question 11.2) which was asked in the survey was the impact of not conducting verifications. Here the consequence of performing verifications of flow meters as perceived by participants was asked about and presented in Table 7. In this column it is noted that 12% of the participants indicated that there would be no impact if verifications did not take place. It was also noted that 25% of participants said that they do not perform verifications while the last 63% indicated that there will be minimal consequences (Less than 1% of the flow meters breakdown and cause downtime etc.) if no verifications are performed as a preventative maintenance.

4.1.3.2.5 Calibrations

The final preventative maintenance activity question (question 12) was related to calibrations. In this question, the basics of calibration was explained in a few sentences.

The first part of the question (question 12.1) the participant had to indicate if calibrations were being performed on flow meters on the plant and the results are seen in Table 6. Here, in the last column it was observed that 43% of calibrations only occur in a reactive manner, i.e. when then instrument fails. The remainder of the participants that answered the question (57%) said that they do perform preventative calibration maintenance (once a day, week, month etc.). This percentage made up the activity with the second most participants indicating that calibrations occur as a proactive maintenance.

The next part of the question (question 12.2) was the consequence for not performing calibration of flow meters perceived by participants. The results can be seen in Table 7. It was observed that 22% of the survey participants indicated that they do not conduct any preventative maintenance. However, only 4% of participants indicated that there will be no impact should no calibrations take place. The rest (74%) indicated that there will be a consequence (More than 5% of the flow meters breakdown and cause downtime etc.) if no calibrations take place. This is the highest number per activity indicating that there will be a consequence if no calibrations take place.

4.1.3.3 Reliability of flow meters

The last part of the questionnaire (question 13) asked the participant to indicate how reliable their flow meters were. This was a close ended question but established the preconceived reliability of the flow meters. The results of the question are presented in a line graph in Figure 10. Here 35 of the participants indicate that reactive maintenance is needed on their flow meters once a quarter, this was the highest amount. Of note, 27 participants indicated that reactive maintenance occurs on their flow meters once a month and 14 indicated once a year. As the line on the graph declines on either side with participants indicated that reactive maintenance occurs less in a day and three yearly or more respectively.

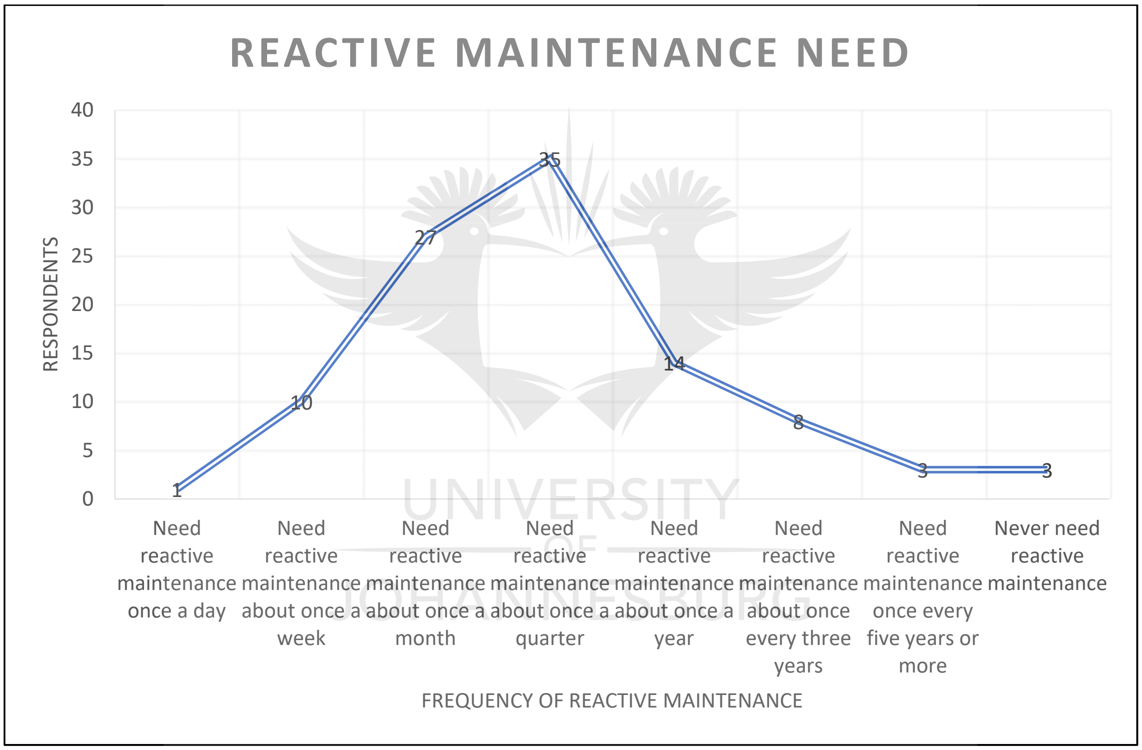

Figure 10: Reliability of flow meters according to survey data

4.1.3.4 Replace/Repair

This question (question 14) asked the participant to indicate what actions they may take when an instrument does happen to fail. As one can see in Figure 11, 53% of respondents indicated repair of the full instrument is what they do when an instrument fails. Just less than half (47%) of participants indicated that they replace the flow meter when it stops functioning.

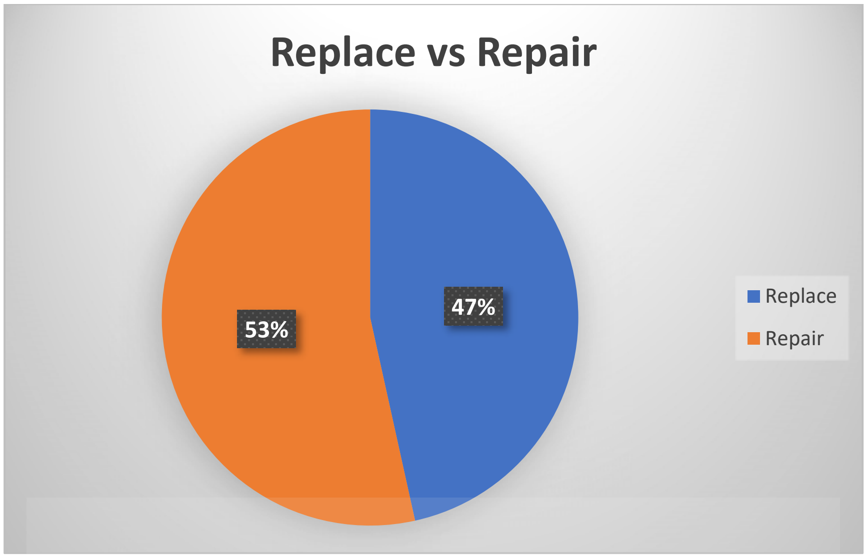

Figure 11: Repair/Replace flow meter according to survey data

4.2 Data analysis

This research looked at the perception of responsible technical personnel towards conducting flow instrument preventative maintenance on the plant.

As clearly defined in chapter 2, Interval timing of preventative maintenance (PM), a system is required in order to determine when the different preventative maintenance activities need to take place, and that, even though there are many different methodologies to determine when to conduct preventative maintenance, it is important that it is completed as a preventative activity. However, looking at the responses, only 47% of technical personnel have a system indicating when preventative maintenance should occur, as seen in Figure 9. The rest of the participants (53%) either did not have system indicating when preventative maintenance needed to occur or were not sure what PM was.

It was made clear that there were 5 types of preventative maintenance activities that had to take place. These types of activities were visual inspection, cleaning, functional checks, verifications and finally calibrations.

These activities as seen in section validation techniques and interval maintenances in chapter 2 indicated that preventative maintenance activities needed to occur on the flow meter in order to extend its life cycle. It also played a vital role in extending the life cycle and uptime of the plant.

The analysis of the data can be broken down into the following three research questions that were set out in chapter 1.

4.2.1 Preventative maintenance activities required on a flow meter

As seen in chapter 2 and in the summary table, Table 1, preventative maintenance activities need to take place regularly. Each preventative activity has a specific reason it needs to be conducted on flow meters.

There are 5 different types of maintenance, all with an importance to preventative maintenance activities. For each activity the following cross tabs were extrapolated from the answered data and is presented below.

4.2.1.1 Visual inspection

As seen in chapter 2, Visual inspection can be conducted by looking at the instrument to find any visible faults or errors. Here it is noted that 48% (48 out of 101) participants conduct this activity only when it fails as seen in Table 8. It can also be seen that 16 out of 48 (33%) participants that indicated 'yes' do have a system conduct visual inspections as a reactive activity. Those that do have a system that indicates when PM should occur often conducted visual inspection once a year, as also seen in Table 6.

Table 8: Visual inspection as preventative maintenance

System that indicates when PM should occur	**N**	**Visual Inspection**							
		Once a day	**About once a week**	**About once a month**	**About once a quarter**	**About once a year**	**About once every three years**	**Once every five years or more**	**When the instrument fails**
Yes	48	0	4	7	8	10	3	0	16
No	27	1	1	5	2	4	0	0	14
I am not sure what preventative maintenance is	26	1	0	3	0	3	0	0	19
Total	101	2	5	15	10	17	3	0	49

The participants that do not have a system however, indicating PM scheduling, 14 out of 27 (52%) of them conduct visual inspection as a reactive event. Finally, the participants that were not sure what preventative maintenance was 19 out of 26 (73%) indicated that they only conducted visual inspections as a reactive event. In the “I am not sure what preventative maintenance is” row the rest of the participants (27%) did conduct preventative maintenance. It was clear to see from Table 8, if the respondent did not have a system or were not sure about the preventative maintenance visual inspection, they were most likely not to perform it.

4.2.1.2 Cleaning

As seen in chapter 2, in Table 3, cleaning of the instrument removes any deposit layer in the instrument’s sensor or the transmitter. There are two methods of cleaning, one physical and the other automatic. From the research conducted and presented in the table below, Table 9 one can see a lot cleaning takes place once a year (18 out of 101) or once a week (13 out of 101). However, if we look at participants that do have a system indicating when preventative maintenance should occur, 15 out of 48 (31%) perform cleaning as a reactive activity.

Table 9: Cleaning Preventative Maintenance

System that indicates when PM should occur	**N**	**Cleaning**							
		Once a day	**About once a week**	**About once a month**	**About once a quarter**	**About once a year**	**About once every three years**	**Once every five years or more**	**When the instrument fails**
Yes	48	1	9	5	5	9	3	1	15
No	27	1	1	5	1	4	2	0	13
I am not sure what preventative maintenance is	26	0	3	0	2	5	1	0	15
Total	101	2	13	10	8	18	6	1	43

What is also noticeable is that 13 out of 27 (48%) and 15 out of 26 (58%) of respondents who indicated that they do not have a system or are not sure what preventative maintenance is conduct cleaning as a reactive activity, respectively. This is a lot higher than if there is a system. However, whether the technical resource has a system or not, 43 out of 101 conduct this activity as a reactive event.

4.2.1.3 Functional Checks

The functionality test, as indicated in chapter 2, Table 1, is conducted by checking how the instrument is operating in the field. This functional test ensures that the flow meter meets process plant output requirements. This is a requirement of preventative activities and from the below table, Table 10, the following survey data is presented.

It is noted that if there is a system that indicates PM should occur, 13 out of 48 (27%) perform functional checks as a reactive event. It is also noted here that 11 out of 48 of participants indicated they conduct functional checks once a year due to a system indicating so.

It there is no system, it is seen that 16 out of 27 (59%) participants indicated that functional checks are done as a reactive activity. However, those that are not sure what preventative maintenance is, 17 out of 26 (65%) of these participants portray that they complete functional tests as a reactive event.

Table 10: Functional tests as Preventative Maintenance

System that indicates when PM should occur	**N**	**Functional Test**							
		Once a day	**About once a week**	**About once a month**	**About once a quarter**	**About once a year**	**About once every three years**	**Once every five years or more**	**When the instrument fails**
Yes	48	0	4	6	9	11	1	4	13
No	27	0	1	1	4	3	2	0	16
I am not sure what preventative maintenance is	26	0	2	1	3	2	1	0	17
Total	101	0	7	8	16	16	4	4	46

In total for functional checks 46 out of 101 of participants indicated that they only perform this activity as a reactive event. The other participants (55), conduct this work as a preventative activity as seen both tables, Table 6 and Table 10.

4.2.1.4 Verifications

A verification, as seen in chapter 2, Table 1, is performed by checking that all the internal electronics as well as the sensor are functioning correctly. This is done by analyzing the sensor to see if it is measuring and often simulating the transmitter of the instrument to see if an adequate output to the plant is being received.

In the table below, Table 11, 46 out of 101 conduct verifications as a reactive activity. This is divided into respondents that do have a system, do not and are not sure what preventative maintenance is. Here 13 out of 48 (27%) who have a system indicated that they complete verifications as a reactive event. Most of the participants however, 19 out of 48, that have a maintenance system indicate that they perform verifications as a preventative activity once a year.

Table 11: Verifications as preventative maintenance

System that indicates when PM should occur	**N**	**Verifications**							
		Once a day	**About once a week**	**About once a month**	**About once a quarter**	**About once a year**	**About once every three years**	**Once every five years or more**	**When the instrument fails**
Yes	48	0	0	3	8	19	4	1	13
No	27	0	0	2	1	5	2	1	16
I am not sure what preventative maintenance is	26	0	0	2	1	5	1	0	17
Total	101	0	0	7	10	29	7	2	46

Verifications from a total perspective, notably seem to occur predominantly once a year, across all the system indications. Here 29 out of 101 participants indicated they conduct verification maintenance once a year.

4.2.1.5 Calibrations

Calibration, as seen in chapter 2, Table 1, is comparing the unit under test (UUT) against a reference unit. Here the Unit Under Test (UUT) is often taken out of the process and becomes an expensive, time-consuming yet essential activity. The deviation between the reference and UUT will indicate how well the instrument is really functioning and if there needs to be an adjustment.

In the table below, Table 12, extrapolated form the survey the following becomes apparent. 13 out of 48 (27%) of participants who have a system indicate that they do calibrations as a reactive activity. It is also noticed that most 18 out of 48 (38%) of participants that have a system, conduct calibrations once a year and another 11 out of 48 (23%) once every three years.

Of note in the table below is that 15 out of the 27 participants who indicate they do not have a PM system perform calibrations as a reactive activity. It is also seen that 16 out of 26 of participants who are not sure what preventative maintenance is conclude that they conduct calibrations as a reactive activity.

Table 12: Calibrations as preventative maintenance

System that indicates when PM should occur	**N**	**Calibrations**							
		Once a day	**About once a week**	**About once a month**	**About once a quarter**	**About once a year**	**About once every three years**	**Once every five years or more**	**When the instrument fails**
Yes	48	0	0	0	3	18	11	3	13
No	27	0	0	2	2	5	3	0	15
I am not sure what preventative maintenance is	26	0	0	0	2	8	0	0	16
Total	101	0	0	2	7	31	14	3	44

Here, similar to verifications, the predominant amount of calibrations, 31 out of 101, occur once a year as a Preventative activity. However, there are still more respondents in total, 44 out of the 101, who indicate that they only perform calibrations when the instrument fails.

4.2.1.6 Concluding results

In the data from the survey and extrapolated in the above sections the following conclusions presented. Out of the 101 respondents, 48 of them said they have a system, 27 said they do not and the final 26 said they are not sure what preventative maintenance is. Of the respondents that indicated they have a system, 35 of the 48 (72%) who performed functional checks, verifications and calibrations do so as a proactive preventative maintenance. These figures can be seen in the tables above as well as in the summary of Table 13 below. However, only 32 and 33 out of the 48 respondents conduct visual inspections and cleaning as a preventative maintenance respectively, this figure being lower here than in other activities. As seen in Table 11, of the respondents that said, they do have a system between, 13 to 16 indicated that they perform these activities when the instrument fails, in other words as a reactive event.

Of the participants that indicated that they do not have a system (27), between 11 and 16 indicated that they perform preventative maintenance proactively. Within functional checks and verifications 11 out of the 27 (41%) indicate that this is a proactive activity. However, a lot of participants as seen in Table 6 and Table 13 indicted they conduct preventative maintenance activities as a reactive event, when the instrument fails. Within verifications and functional checks 16 out of the 27 (59%) indicated that these activities were reactive.

As seen in the above sections, some (26 of the 101) of the participants indicated that they are not sure what preventative maintenance is. Within this, (as seen in Table 13, 7 to 11) of the participants indicated that these activities were actually done proactivity, with cleaning being the 11 out of the 26 (42%). However, the majority of participants indicated that each activity was performed more as a reactive event on flow meters than a proactive one. In visual inspections column 19 of the 26 (73%) indicated that their inspections would only happen as reactive.

In concluding this section, it was noted that the survey indicated that 100% of participants were responsible for preventative maintenance on their respective plants. The results also indicated that 57% of participants worked on a plant that were between 10 and 30 years old, indicating an aging plant as seen in Figure 7. The research in chapter 2, Preventative maintenance activities on flow instruments, it is noted that these activities should be occurring 100% of the time. However, as seen in the above and the below tables, these activities more than often occur as a reactive event.

As seen in Table 13, a lot of the activities, even though intended as a preventative activity are conducted as a reactive event. In total, between 43 to 49 out of 101 of the participants indicated that these activities occur as a reactive. With 43 (43%) indicating this on cleaning and 49 (49%) indicating this on visual inspections.

Table 13: PM activities as planned vs Reactive (When instrument fails)

System that indicates when PM should occur	N	Visual Inspection		Cleaning		Functional Test		Verifications		Calibrations	
		Total Conducting PM activities (Includes all Times)	When instrument fails	Total Conducting PM activities (Includes all Times)	When instrument fails	Total Conducting PM activities (Includes all Times)	When instrument fails	Total Conducting PM activities (Includes all Times)	When instrument fails	Total Conducting PM activities (Includes all Times)	When instrument fails
Yes	48	32	16	33	15	35	13	35	13	35	13
No	27	13	14	14	13	11	16	11	16	12	15
I am not sure what preventative maintenance is	26	7	19	11	15	9	17	9	17	10	16
Total	101	52	49	58	43	55	46	55	46	57	44

4.2.2 Impact of not conducting preventative maintenance flow meters

As seen in the research question two, RQ2, what is the impact on the plant should preventative maintenance activities not take place on the measuring instrument, the following results were obtained and analysed from the survey.

In Chapter two it was indicated that 5 different preventative maintenance activities had to take place otherwise there would be specific consequence on the plant and on the instrument. The summary table, Table 3, indicated the summarized impact if no preventative maintenance occurs.

Table 14: Impact of not conducting Preventative maintenance

	Visual inspections	Cleaning	Functional Checks	Verifications	Calibrations
Less than 1% of the flow meters breakdown and cause downtime	19	17	14	15	18
between 1% and 3% of the flow meters breakdown and cause downtime	13	20	30	27	18
between 3% and 5% of the flow meters breakdown and cause downtime	16	12	13	13	26
More than 5% of the flow meters breakdown and cause downtime	8	15	8	9	13
No impact	10	7	9	12	4
I do not perform visual inspections on my plant	35	-	-		
I do not clean flow meters on my plant	-	30	-		
I do not perform functional tests on my plant	-	-	27		
I do not perform verifications on my plant	-	-		25	
I do not perform calibrations on my plant	-	-			22

In Table 14 above, shows the perceived impact of not conducting different preventative maintenance activities. Here 19% (19 out 101) indicated that by not doing visual inspection less than 1% of the flow meters breakdown and cause downtime. In cleaning and in functional check 20% (20 out of 101) and 30% (30 out of 101) indicate that not doing these PM activities affects 1% to 3% of their flow meters breakdown respectively. Even though the second highest in verifications is like that of cleaning and functional checks, calibrations are slightly different. In Calibrations 26% (26 out of 101) indicated that if no calibrations were completed as a PM it would affect 3% to 5% of their flow meters and cause down time, which is a significant number.

Even though most respondents in each activity state that they do not conduct certain preventative maintenance activities and it is therefore presumed they are not aware of the impact.

4.2.3 Perceived importance of flow meter preventative maintenance

Research question 3 (RQ3) in chapter 1 asks if preventative maintenance on flow instrumentation is perceived as important to the technical personnel. This was a deduction from a few questions in the survey as well as some research presented in chapter 2 and the data analysed in the above sections.

In question 5, it considered that every person (100%) answering the survey indicated that they are responsible for maintaining instrumentation on their plant. However, 11% (Figure 8) of technical personnel did not know how many flow meters they had on their plant. It could also be seen (Figure 7) that 66% of respondents indicate that their plant was more than 10 years old, and therefore a change in frequency of preventative maintenance needed to occur.

In addition to this, it is also seen in Table 6 and Table 7 that there is a contradiction between participants who view the importance of preventative maintenance and conduct this as a priority. There are less technical personnel that conduct preventative maintenance proactively than the number knowing there is a perceived consequence. This is further discussed in in Chapter 5, Summary of results to research question 3.

4.3 Conclusion

Chapter four presented the data from the questionnaire survey. A total of 101 respondents completed the survey.

It can be concluded that even though it was recognised that preventative maintenance needs to be conducted, and that the 5 different activities should take place in order to prolong the life cycle of the flow meter, as seen in Table 6, only just over half of the participants (52% - 58%) conduct flow meter preventative maintenance proactively. The other participants (42% - 48%) only perform these activities as reactive. It is also noted from Table 7, that between 74% and 56% of participants indicated that there is a consequence of not conducting preventative maintenance.

The following chapter, chapter 5, draws comprehensive conclusions based on the survey results, the literature review and provides conclusions and recommendations for the research topic.

Chapter 5

5 Discussion of results

The purpose of this chapter is to discuss the results obtained from the data analysis. A summary of the problem statement and the research questions is presented. The aim of this minor dissertation was to address the following problem, as stated in chapter 1: **Preventative maintenance of flow measuring instruments on the plant is not perceived to be a priority by the responsible technical personnel.**

Three research questions were formulated to assist in answering the problem statement above. The answer to the research questions were obtained through literature review, data collection using an online survey as well as the data analysis.

Preventative maintenance is the activity of cleaning, inspecting, performing functional checks, verifications and conducting calibrations on an instrument to check that the unit is operating correctly (Khan and Haddara, 2003; Toteva, Slavov and Vasileva, 2017). All these activities are placed together in order to ensure that instruments perform, the plant runs at a required optimal output and process of Preventative maintenance is prioritised. These activities are often considered the life line of any plant and are essential (Ma, Sun and Mathew, 2007).

This chapter will discuss the presented results by comparing them with literature. The last section of this chapter contains the conclusion of all the results and recommendations of what the research determined.

5.1 Summary of results

The three questions that assisted in the completion and the answering of the problem statement were as follows

> **RQ1:** What are the preventative maintenance activity practices required on a flow measuring instruments in a plant?
>
> **RQ2:** What is the impact on the plant should preventative maintenance activities not take place on flow measuring instruments?

RQ3: Is preventative maintenance on flow instrumentation perceived as important by the technical personnel.

The results and conclusions obtained using the survey answered these three questions and hereby answered the problem statement. These conclusions are presented in summary below.

5.1.1 Summary of results to research question 1.

What are the preventative maintenance activity practices required on a flow measuring instruments in a plant?

Literature presented five preventative maintenance activities required on flow meters. These maintenance activities include visual inspection, cleaning, function check, verification and calibrations of flow meters. These different preventative maintenance activities all need to occur, even if they do occur at different frequencies as determined by a certain maintenance scheduling system. The occurrence of these preventative maintenance activities means that the flow meter instrumentation is being maintained and looked after. It also means that the life cycle of the instrument as well as the plant will improve. However, on the process plants in the SADC region, these activities do not always occur. Even though 100% of respondents were responsible for instrumentation, only between 52% and 58% of participants proactively conducted preventative maintenance. This figure can be seen in the above tables, especially Table 6, as well as in summary in Table 15.

Table 15: Proactive PM vs reactive work summary table

Frequency of preventative maintenance	Visual inspections	Cleaning	Functional checks	Verifications	Calibrations
Proactive maintenance total	52%	58%	55%	55%	57%
When the instrument fails (reactive)	48%	42%	45%	45%	43%

Table 15 demonstrates that 48% of participants only conduct visual inspection as a reactive event. What was also seen from the survey results is that only 48 out of the 101 participants had a system to tell them when to conduct preventative maintenance and there was always more than 13 technical personnel per activity that indicated, that they complete the activity reactively, rather than preventatively, as seen in Table 13.

The activities are clearly defined in literature as preventative maintenance; however, from the data it can be concluded that only half of the respondents implement these activities proactively, that is, implement them in the form of presentative maintenance.

5.1.2 Summary of results to research question 2

What is the impact on the plant should preventative maintenance activities not take place on flow measuring instruments?

The five preventative maintenance activities, as seen from RQ1, need to take place. However, the consequences of not conducting such activities become apparent. These include the life cycle of the instrument being reduced, downtime of the plant, amount of money used, uncertainties in measurement and increase in reactive maintenance time and cost, as seen in Table 3 in chapter 2. The results from the survey, Table 7, showed that around 56% to 74% of participants indicated that there will be an impact should these preventative maintenance activities not occur. As seen in Table 16 in summary below, it is observed that 74% of participants indicated there will be an impact on their plant should calibrations not occur.

Table 16: Not conducting PM has an impact on the plant

Impact of Preventative Maintenance	Visual inspections	Cleaning	Functional Checks	Verifications	Calibrations
There is an impact total	56%	64%	64%	63%	74%

In conclusion, the technical personnel indicated that they are aware that there is an impact on the plant and on flow meters should preventative maintenance not occur as seen above.

5.1.3 Summary of results to research question 3

Is preventative maintenance on flow instrumentation perceived as important by the technical personnel?

Data analysed, and some research indicated that the perception of technical personnel towards conducting preventative maintenance activities on flow meters was that it is not a priority. Within the questions and from chapter 4, section 4.2.3, one can see this presented. The contradiction between the proactive preventative maintenance and the impact no maintenance will have on the plant is presented.

The information in Table 15 and Table 16 has been summarised in Table 17 below.

Table 17: Proactive maintenance total vs impact total from survey data

	Proactive PM total	There is an impact total
Visual inspections	52%	56%
Cleaning	58%	64%
Functional Checks	55%	64%
Verifications	55%	63%
Calibrations	57%	74%

From this table, it can be seen that an average of about 55% of technical personnel conduct preventative maintenance as a proactive activity. The other 45% of participants conduct this as a reactive event. In addition to this, an average of 64% of the participants indicated there is a consequence for not conducting preventative maintenance. One aspect that stands out from the above table was calibrations: here participants indicated that proactive preventative maintenance occurred 57% of the time, but 74% of them indicated if this preventative maintenance did not occur this would affect their flow meters and thus their plant. These figures present a contradiction. They highlight that the perceived lack of importance to conduct preventative maintenance, which is accompanied by a failure to undertake such maintenance, exists in the minds of technical personnel despite an understanding of the problems or consequences of not doing preventative maintenance.

5.2 Conclusions

The key results derived from this research have answered the research questions posed and have thereby addressed the problem statement. The problem was: **The responsible technical personnel perception towards conducting flow measuring instrument preventative maintenance on the plant is not a priority.**

If preventative maintenance is not conducted proactively and timeously, problems start to occur on the plant. The consequences of these problems are known to impact the plant.

However,45% of technical personnel do not conduct maintenance proactively while 64% know that there is an impact on the plant because of this. It is thus concluded from the above questions and statement, that preventative maintenance of flow meter instrumentation is indeed not viewed as a priority in all types of plants studied in the SADC region.

5.3 Recommendations

There are a few recommendations that are arise from this research. These recommendations are listed below:

- A drive to explain the importance of maintenance to technical personnel needs to take place. Not only the value on flow meters but on all the components and machines on process plants. This drive could focus on advocating cultural changes, education as well as a changed management approach. Perhaps to note, the importance of preventative maintenance on cars, our bodies and even our environments is crucial and even though there are recommendations on what to do, this does not happen adequately. This is not solely about education, but also about behaviour change of people, specifically in this case technical personnel looking after the flow meters on the plant. This can be seen in the priority to perform preventative maintenance on these instruments.
- A greater emphasis needs to be made on preventative maintenance activities in plants in the SADC region. One way of addressing this could be an understood presented workflow process introduced in the plant. This workflow will enable technical personnel to follow a step wise process in conducting such maintenance. An example is supplied in Appendix B.
- The implementation of a preventative maintenance system by technical experts, indicating what preventative maintenance activity to do when, based on process medium, application and criticality of flow meters. This system however needs to have the full confidence and buy in of the technical personnel responsible for the flow instrumentation maintenance by applying change management or a cultural adjustment.
- Retract from a replacement mentality (48% of respondents replace the full flow meter) to one of repair and maintain. The replacement mentality induces a reactive

and wasteful culture where flow meters can be replaced instantly, without proper care and preventative maintenance. A cost analysed of repairing an instrument vs replacing the whole instrument in the SADC region could also be completed.

5.4 Limitations

This paper had some limitations, and these are presented below

- The sample size was small, only 101 respondents answered the survey questionnaire.
- There was little to no research that could be found on the perceptions of personnel towards the priority of preventative maintenance on flow meters, thus making literature review for RQ3 challenging. It is not known if such information has simply not been published, or is published in the grey literature, or whether this was a failure to discover material.
- Not all flow meters can have extensive preventative maintenance activities undertaken on them; for some (rotameters), only a basic check can take place. Thus, participants may have had those in mind when they indicated certain activities are not completed.

5.5 Possible future research

The following possibilities for further research arising from this paper could be considered:

- A study into the understanding of why preventative maintenance is not perceived to be important.
- The culture of technical staff in reactive maintenance and the reasons for replacing an instrument rather than repairing it.
- Systems and procedures to help improve preventative maintenance and the perception of technical personnel regarding this.
- How can the system of preventative maintenance scheduling and decision making be strengthened and understood?
- Preventative maintenance activities on other instruments and control and the perception towards the maintenance of these.

- The introduction of predictive maintenance is at the foreground of process plants (Carnero, 2006); however if proactive preventative maintenance is not viewed as important, will the inclusion of predictive maintenance be viewed similarly?
- Which obstacles, including safety, prevent technical personal from conducting preventative maintenance despite knowing that there are consequences for this.

6 References

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Appendix A: Research Questionnaire

To: Participant

I am a masters (in Engineering Management) student at the Faculty of Engineering and the Built Environment at the University of Johannesburg. As part of my studies, I am conducting research on how flow instrumentation preventative maintenance is carried out on different plants in the SADC (Southern African Development Community) region. The research will investigate the importance of conducting flow instrumentation preventative maintenance and the impact of conducting such maintenance.

It is envisaged that the information obtained from this research will positively impact on plants in the SADC region. Your assistance with this questionnaire will make a real contribution to the accuracy and success of this research. Participants are guaranteed that this survey is both confidential as well as anonymous. Your assistance is vital and there are no wrong or right answers. No information regarding your plant, your team, manager or organization will be disclosed.

You will not be required to enter any personal particulars for the questionnaire. Your participation is voluntary and involves no risks, sanctions or loss of benefits whether you participate. You may with withdraw your survey answers at any stage.

You will find a link attached to these questions.

Your contribution towards this is highly valued.

Yours Faithfully

Timothy Couper

timmy008@gmail.com

RETHINK. **REINVENT.**

UNIVERSITY OF JOHANNESBURG

Ethics Approval Clearance Certificate

The ethics approval application submitted by

Name of Researcher	Timothy David Crouper
Name of Organization	University of Johannesburg
Name of Faculty	Faculty of Engineering and the Built Environment
Name of Principal Investigator	Prof Annlize Marnewick
Name of the Research Project	The perspective of the importance to conduct preventative flow meter instrumentation maintenance on production plants in the SADC region.

Has been

[X] APPROVED without the need for any modification by the Ethic Committee.

[ ] APPROVED in principle but requires modification / additional information as indicated below in the comments section by the Committee.

[ ] NOT APPROVED and requires modification / additional information as indicated below in the comments section by the Committee. Resubmission is required before approval can be granted.

[ ] DISAPPROVED without the possibility for resubmission – the information indicated below in the comments section by the Committee highlights the reasons for this decision.

Signature (Chair of the FEBE FEPC)

March 31, 2020
Date of FEBE FEPC meeting

Questions

These questions will be proposed online through Survey Maker

1. Please indicate your role on the plant

Please use a tick (√) next to your answer

	Role on plant	Please tick appropriate box
	Engineering Maintenance Manager	
	Automation Engineer	
	Technical Resource (e.g. Instrumentation Technician, Maintenance team member)	
	Artisan	

2. Please select the country you are working in

Please use a tick (√) next to your answer

Angola	
Botswana	
Comoros	
Democratic Republic of Congo	
Eswatini	
Lesotho	
Madagascar	
Malawi	
Mauritius	
Mozambique	
Namibia	
Seychelles	
South Africa	

United Republic of Tanzania	
Zambia	
Zimbabwe	

3. In what industry do you work in

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Food and Beverage	
2	Water/Wastewater Treatment Plant	
3	Mining, Minerals and Metals	
4	Oil and Gas	

4. How old is the plant you are working on?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 5 years old	
2	Between 5 and 10 years old	
3	Between 10 and 30 years old	
4	More than 30 years old	

5. Please indicate if your role is responsible for plant instrumentation on your site

Please use a tick (√) next to your answer

	Please tick appropriate box
Yes	
No	

6. How many flow measuring instruments do you have on your plant?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 200	
2	Between 200 and 500	
3	Between 500 and 1000	
4	Between 1000 and 2000	
5	Over 2000	
6	Unknown	

7. Do you have a system that indicates when you need to perform various preventative maintenance activities on these flow meters?

Please use a tick (√) next to your answer

1	Yes	
2	No	
3	I am not sure what preventative maintenance is	

8. Visual inspections are conducted by looking for any obvious dents, error messages on the display and that the instrument is installed correctly etc.

8.1. Of these flow meters, how often do you perform a visual inspection?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Once a day	

2	About once a week	
3	About once a month	
4	About once a quarter	
5	About once a year	
6	About once every three years	
7	Once every five years or more	
8	When the instrument fails	

8.2. What are the impacts on the plant if no visual inspection is performed in a timeous manner?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 1% of the flow meters breakdown and cause downtime	
2	between 1% and 3% of the flow meters breakdown and cause downtime	
3	between 3% and 5% of the flow meters breakdown and cause downtime	
4	More than 5% of the flow meters breakdown and cause downtime	
5	No impact	
6	I do not perform visual inspections on my plant	

9. Flow measuring instruments need to be cleaned on the outside as well as sometimes the measuring sensor.

9.1. Of these flow meters, how often do you clean the instrument?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Once a day	
2	About once a week	
3	About once a month	
4	About once a quarter	
5	About once a year	
6	About once every three years	
7	Once every five years or more	
8	When the instrument fails	

9.2. What are the impacts on the plant if no cleaning is performed in a timeous manner?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 1% of the flow meters breakdown and cause downtime	
2	between 1% and 3% of the flow meters breakdown and cause downtime	
3	between 3% and 5% of the flow meters breakdown and cause downtime	
4	More than 5% of the flow meters breakdown and cause downtime	
5	No impact	
6	I do not clean flow meters on my plant	

10. The functionality test is conducted by checking how the instrument is operating in the field.

10.1. Of these flow meters, how often do you perform a functional test?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Once a day	
2	About once a week	
3	About once a month	
4	About once a quarter	
5	About once a year	
6	About once every three years	
7	Once every five years or more	
8	When the instrument fails	

10.2. What are the impacts on the plant if no functional test is performed in a timeous manner?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 1% of the flow meters breakdown and cause downtime	
2	between 1% and 3% of the flow meters breakdown and cause downtime	
3	between 3% and 5% of the flow meters breakdown and cause downtime	
4	More than 5% of the flow meters breakdown and cause downtime	
5	No impact	

6	I do not perform functional tests on my plant	

11. A verification is performed by checking that all the internal electronics as well as the measuring sensor are functioning correctly.

11.1. Of these flow meters, how often do you perform a verification?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Once a day	
2	About once a week	
3	About once a month	
4	About once a quarter	
5	About once a year	
6	About once every three years	
7	Once every five years or more	
8	When the instrument fails	

11.2. What are the impacts on the plant if no verification is performed in a timeous manner?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 1% of the flow meters breakdown and cause downtime	
2	between 1% and 3% of the flow meters breakdown and cause downtime	

3	between 3% and 5% of the flow meters breakdown and cause downtime	
4	More than 5% of the flow meters breakdown and cause downtime	
5	No impact	
6	I do not perform verifications on my plant	

12. Calibration is comparing the flow measuring unit to a traceable standard and sometimes performing adjustment to ensure the instrument becomes more accurate.

12.1. How often are these flow meters calibrated?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Once a day	
2	About once a week	
3	About once a month	
4	About once a quarter	
5	About once a year	
6	About once every three years	
7	Once every five years or more	
8	When the instrument fails	

12.2. What are the impacts on the plant if no calibration is performed in a timeous manner?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Less than 1% of the flow meters breakdown and cause downtime	
2	between 1% and 3% of the flow meters breakdown and cause downtime	
3	between 3% and 5% of the flow meters breakdown and cause downtime	
4	More than 5% of the flow meters breakdown and cause downtime	
5	No impact	
6	I do not perform calibrations on my plant	

13. How reliable are these flow meters?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Need reactive maintenance once a day	
2	Need reactive maintenance about once a week	
3	Need reactive maintenance about once a month	
4	Need reactive maintenance about once a quarter	
5	Need reactive maintenance about once a year	
6	Need reactive maintenance about once every three years	

7	Need reactive maintenance once every five years or more	
8	Never need reactive maintenance	

14. When a flow meter suddenly stops operating do you replace the unit or go through steps to try to repair it?

Please use a tick (√) next to your answer

		Please Tick the Appropriate box
1	Replace	
2	Repair	

Appendix B: Operational flow diagrams

The following operational flow charts were established from the survey as well as the literature review. Each of these flow diagrams related to the preventative maintenance that was required by a flow instrument. These could be used to improve the preventative maintenance on flow meters, and the perception towards this.

Preventative Maintenance activities flow chart

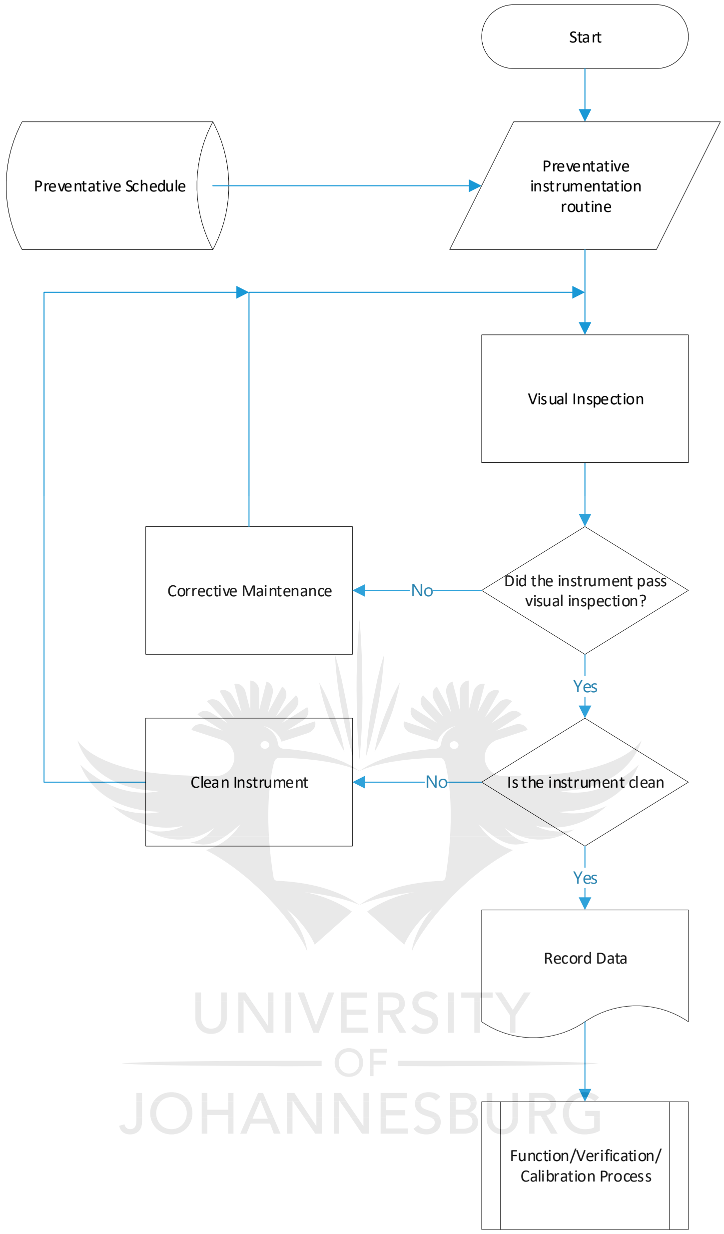

Figure B.1: Preventative Maintenance Activities flow chart

Functional; Verification and Calibration Process

The below process describes the workflow to conduct functional, verification and calibrations process, these are represented in sub-processes.

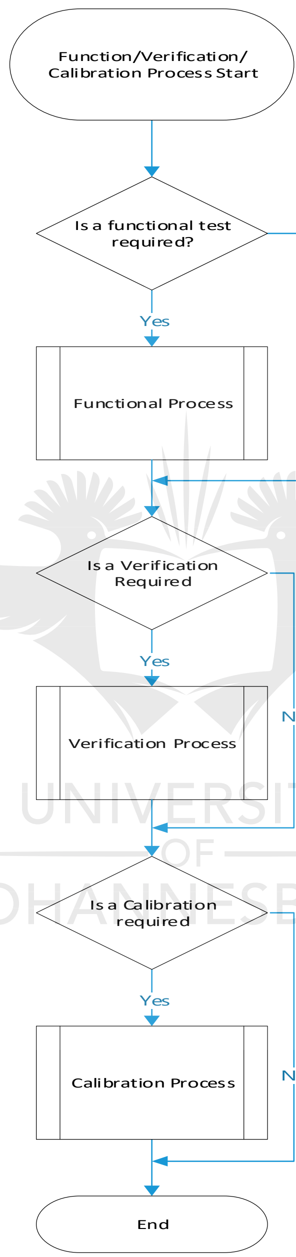

Figure B.2: Functional; Verification and Calibration process

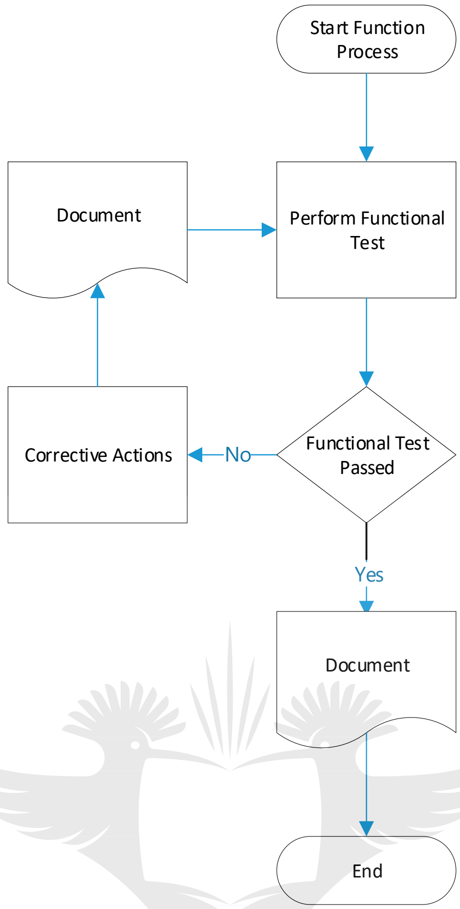

Figure B.3: Sub-process functional test

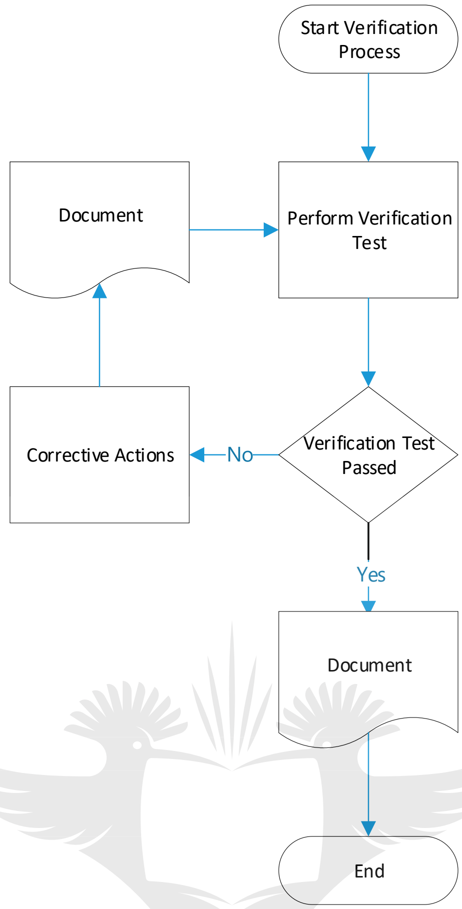

Figure B.4: Sub-process verification

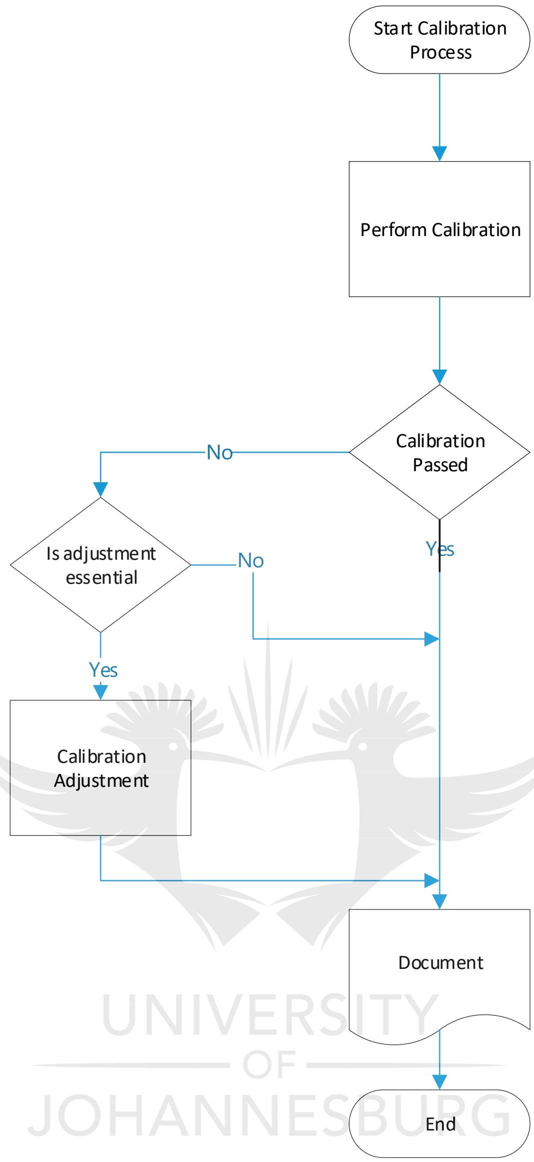

Figure B.512: Sub-process calibration