UNIVERSITY OF JOHANNESBURG

QUALITY CONTROL IN A UNIVERSITY LABORATORY: A STUDY OF ISO/IEC-17025 IMPLEMENTATION IN THE THIN SECTION LABORATORY

CEBEKHULU BMB

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LIST OF ABBREVIATIONS/ACRONYMS

IEC	International Electro-Technical Committee
ISO	International Organisation for Standardisation
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System
QS	Quality System
R&D	Research and Development
ROI	Return on Investment
SEM	Scanning Electron Microscope
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

DECLARATION

This serves to confirm that I, Bongumusa Mansuette Bhekamalinda Cebekhulu

Student number 201132191 enrolled for the Qualification M-Tech Operations Management in the Faculty of Engineering and the Built Environment, hereby declare that my academic work is in line with the Plagiarism Policy of the University of Johannesburg with which I am familiar.

I further declare that the work presented in the dissertation is authentic and original unless clearly indicated otherwise and in such instances full reference to the source is acknowledged and I do not pretend to receive any credit for such acknowledged quotations, and that there is no copyright infringement in my work. I declare that no unethical research practices were used or material gained through dishonesty.

Signed: Bongumusa Cebekhulu

Date: 20/08/2016

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ABSTRACT

Quality management systems in research and teaching laboratories are difficult to implement due to various reasons and factors. The benefits that the implementation of such systems bring to testing and calibration laboratories make a compelling case for their deployment in teaching and research laboratories as well. The Thin Section laboratory, based at Wits University's School of Geosciences is a research and teaching laboratory. The laboratory has funding and quality challenges and has to find ways of supplementing the grant it receives from the University. One of the ways identified is providing commercial testing services to other sectors. Testing and calibration laboratories are required to conform to ISO/IEC 17025:2005 standard which is the general requirements for the competence of calibration and testing laboratories. The Thin Section laboratory will have to comply with this standard to improve the quality of the products and to be able compete with other testing laboratories.

Making use of laboratory experiments, surveys and interviews, this study aimed to evaluate the gap between the Thin Section laboratory processes and ISO/IEC 17025:2005 requirements, assess the ISO/IEC 17025 implementation challenges for such laboratories and evaluate the possible benefits of implementing such a system. The study found the gap between ISO/IEC 17025:2005 requirements and laboratory procedures to be wide but also recommended solutions to overcome implementation difficulties particular to this laboratory setting and narrowing the identified gap. This study also found that the benefits of implementing ISO/IEC 17025 in this laboratory will, in the long run, outweigh the cost associated with implementation. The findings of this study can be utilised by other teaching and research laboratories, who have intentions of implementing ISO/IEC 17025, to identify challenges inherent with this type of environment and how best to overcome them.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The Thin Section Laboratory produces polished thin sections, used for petrographic studies, thick sections, used in fluid inclusions analysis, and ore blocks for research and teaching purposes in an academic institution. These thick and thin sections can be prepared from core samples, different rock material samples, unconsolidated material (loose sands, soils, aggregates, etc.). The standard thin section size is 26 × 46 mm, with other sizes available on request and depending on preparation instruments and technician capabilities. Thin sections can be covered if required. The thin section laboratory possesses advanced equipment currently available for thin section preparation. The procedures used for section preparation can be adapted depending on the nature of the sample and the objectives and requirements of the client. The laboratory is equipped with various instruments required for the preparation of geological samples. The big diamond saw to cut through large samples of different shapes of rock material, the core splitter cuts and trims core samples into optimum sizes for further processing and trim saws for precise sample-cutting and trimming. The laboratory uses water and other cooling aids for sawing to suppress dust and reduce heat generation. Samples are impregnated in epoxy prior to sectioning. This is done to ensure that all the pores in the rock are filled up so that the sample will have smooth and flat surfaces to allow for mounting. The Thin Section Laboratory prides itself in its ability to produce a large number of quality sections in fast turnaround times.

1.2 Background and Justification

The thin sections and other specimen types prepared in the laboratory can be used for a number of different applications and supplementary analysis. Those include X-ray diffraction (XRD); XRD enables the identification of minerals present in a sample and can be used to support petrographic studies and Scanning Electron Microscope (SEM). SEM analyses are useful, particularly for minerals of small particle size (such as clays or cement), for refining mineralogy and porosity characterizations, and identifying opaque mineral phases. Preparing good quality thin sections is very important for the above-mentioned studies and many other applications to be possible. Most of these analyses depend on the size and thickness of the section as minerals'

optical characteristics sometimes change with size. There is a need to improve the quality, accuracy and precision of the sections the laboratory produces.

The laboratory is housed within an academic institution and has been in operation for many years with the primary objective of producing good quality thin sections for academic research and students' practical work. The price adjustments at the laboratory are always kept to a minimum in order to enable the laboratory users to have as much analytical data available as possible. Increasing student numbers and research activity has led to an increase in the number of sample submissions and the amount of work that has to be processed through the lab. This adds a lot of pressure on the equipment available, laboratory consumables and the technicians operating in the laboratory. Accepting work from other sectors and charging commercial rates will enable the laboratory to create a separate income stream for its operations. The capital generated from commercialising some of the laboratory's services means the laboratory can fund its own minor equipment needs and also offer a percentage contribution when applying for major equipment funding. There will also be money available to buy equipment parts and scheduled equipment services can be carried out without putting more pressure on the laboratory's finances.

1.3 Statement of the Problem

Increases in consumables' prices, the need to purchase advanced technology thin section preparation equipment and high competition for faculty funding has led to the laboratory having to find an additional income stream to sustain itself. The laboratory will make its services available to the industrial sector and charge commercial rates. Most organisations in the industrial sector require service providers to be ISO accredited and for that reason, a quality management system for the laboratory operations needs to be implemented. This study will explore the implementation of ISO 17025 in the Thin Section Laboratory taking into account the cost implications and the possible benefits of implementation. The result and/or findings will be used to assess the gap between laboratory procedures and ISO 17025 requirements and to evaluate whether the thin section laboratory can get ISO 17025 accredited. It can also be used by other university laboratories that may be looking at getting a formal quality management system (QMS).

1.4 Objectives of the Study

- To conduct a Gap analysis of quality management in the thin section laboratory in relation to the requirements of ISO/IEC 17025:2005
- To assess whether there is scope for ISO 17025 implementation in this type of laboratory
- To evaluate whether ISO 17025 is the right standard for the thin section laboratory
- To review quality control measures on thin section production and standardise them.

1.5 Research Questions

a) To what extent does the current management of quality at the thin section laboratory meet the requirements of ISO 17025?
b) Is ISO/IEC 17025 the right standard to utilise in this type of laboratory?
c) Is there scope for the deployment of a formal quality management system in this type of laboratory?
d) Are there parts of the Thin Section making process that can be improved to ensure better quality products?

1.6 Significance of the Study

University laboratories are under constant pressure to justify their existence since there are laboratories that commercially offer the same services. This is more evident whenever fund allocation discussions are held and as a result, there is a need for university laboratories to be self-sustaining. Investigating the implementation of a quality management system for the laboratory will assist the laboratory with improving the quality of the work processed through the laboratory, undertake cost-saving exercises and possibly access more work contracts. Accessing more work contracts will create an additional income stream for the laboratory to compliment the grant it receives from the university.

1.7 Scope of the Study

Quality management systems are a rarity in university laboratories involved in processing teaching material, research and development. This study will look at how

the implementation of a quality management system in the thin section laboratory can assist it to overcome its quality and financial challenges. It will be conducted in the thin section making laboratory but the research/results and findings will not be limited to use for this type of laboratory only. It will try and highlight how implementing ISO 17025 can benefit the thin section laboratory in improving the quality of their products and subsequently attract new clients to supplement their income stream.

1.8 Conclusion

This chapter introduced the thin section laboratory, the services the laboratory provides, challenges that the laboratory is facing and why the implementation of ISO/IEC 17025 can provide solutions to those challenges. The subsequent chapters will delve deeper into different reasons why organisations implement formal QMS, the challenges they faced with implementation and the benefits achieved after implementation. That will be done in relation to the thin section laboratory's situation to illustrate the common and despairing features between other organisations' and the thin section laboratory's reasons for wanting to implement ISO/IEC 17025 and if the benefits of implementation are in line with what the thin section laboratory hopes to achieve.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Quality management system (QMS) implementation is initiated by various factors and it brings with it many benefits while also posing many challenges. Most of these benefits and challenges are organisation-dependent. This chapter will look at the various reasons why different organisations implement formal QMS, the benefits organisations stand to gain from implementing such a system and the challenges organisations face during implementation. Understanding the factors that influence formal QMS implementation in organisations, the challenges and benefits that come with the implementation will assist the thin section laboratory with defining the scope for ISO/IEC 17025 implementation in this type of laboratory and aid the laboratory with making better preparations. Literature also provides guidelines on how to implement formal QMS for different types of laboratories and identifies challenges inherent with the implementation in various types of laboratory settings. This will aid the thin section laboratory with devising possible solutions to anticipated challenges.

2.2 Formal QMS Implementation in University Laboratories

Grochau and Ten Caten (2012) state that the introduction of formal quality management systems (QMS) and getting ISO/IEC 17025 accreditation for laboratories are not simple tasks, even more so for laboratories situated in teaching and research institutions. The university environment has different settings to other laboratories and with that comes a different set of challenges. Not having conventional organisational structures and laboratories being, at most times, staffed by student technicians are just some of the examples of those challenges. Grochau et al. (2012) further posit that the difficulties in implementing formal QMS at university laboratories arise out of the peculiar characteristics of these environments, including the unclear definitions of the functions and responsibilities and the presence of temporary staff. The motivation for implementing a formal QMS at a university laboratory may not be very clear and it is also difficult to measure the impact of accreditation of such laboratories on the quality of human resources education, their innovation capacity, the results of their research, and the quality and quantity of their publications.

Zapata-Garcia, Llaurado and Rauret (2007) posited that the unfavourable setting and environment make formal QMS implementation in a university institution a difficult task.

The particularities being the collaboration of different independent units of the university, and involving many teachers and young researchers to coordinate all the different tasks which introduce higher chances of variation. There is also an unusually high staff turn-over at university laboratories caused by the deployment of student technicians who leave to pursue other interests and technicians who leave for more lucrative positions with the private sector. This leads to the constant changing in personnel and never ending need to train new staff. Due to these factors, university laboratories end up depending on new staff to perform critical tasks when they are not completely competent, a challenge the thin section laboratory also faces.

Understanding how university laboratories operate, Rauret et al. (2003) provided some guidelines for implementing ISO/IEC 17025:2005 at university laboratories. The implementation should be the general goal with technical management, economic management, laboratory performance and the quality of the teaching/learning process as the four specific aims of implementation. If this can be done successfully, all the functions of the thin section laboratory would benefit from the implementation of ISO/IEC 17025:2005.

2.3 Reasons for Implementing Formal QMS in University Laboratories

The implementation of a formal QMS in any organisation could result out of internal desire, external pressure or even institutional strategic planning Grochau et al. (2012). The thin section laboratory's investigation into implementing ISO/IEC 17025 was initially born out of internal desire, and institutional strategic planning, that is: the need to improve the laboratory products and the plan to start offering testing services to the industrial sector and supplement the laboratory's capital. Later, it also became about aligning the departmental goals to that of the university. The university has a goal of being in the top 100 universities in the world. One of the means of achieving that goal is through good research output and research facilities within the university play a major role in the number of publications and quality of research the department produces. The laboratory's plan of offering testing services to the industrial sector also led to the discovery of the external pressure that is sometimes exerted by the industrial sector companies on its service providers to be ISO accredited.

2.3.1 External Pressure

Grochau et al. (2012) states that the greatest motivation for the implementation of a formal quality management system and accreditation of laboratories in teaching and research institutions is the external pressure, which often comes from an external customer or from regulatory agencies. Some clients insist on sending work to accredited laboratories and laboratories without formal accreditation would then lose out on a chance to expand their network. This also impacts on the laboratory's finances because additional work processed through the lab contributes to the financial wellbeing of the facility. Hullihen and Fisch (2009) state that university laboratories are increasingly being asked to perform testing for outside companies which increases scrutiny and exerts added pressure on them to obtain ISO certification. Add to that the accelerating need for industries to prove that their services match or exceed a measurable standard. Vermaecke (2000) posits that since production and service industries take Total Quality Management (TQM) principles seriously, the domino effect of that is that their subcontractors like universities and research institutes, should also follow quality principles. The thin section laboratory would benefit greatly from implementing ISO/IEC 17025 as it would be able to measure its services against a widely accepted standard and also create the opportunity to provide services to other sectors.

Fernandez, Bacchi, Tagliaferro, Gonzaga, De Franca, Favaro and Fogaca (2006) state that test services for external customers are usually provided to generate additional capital and to create clear awareness about the need for systematic quality assurance/quality control actions. Offering these services is usually not a high priority within most university laboratories as laboratory performance is usually measured by the number of samples processed and not their quality. Therefore, the implementation of a quality system is often not prioritised leading to postponement. The cost of such postponements is usually felt down the line when there are product quality related complaints or when there is an opportunity to work on a bigger project but the laboratory cannot capitalise on it because the holding organisation requires ISO accreditation. Vermaercke (2000) further posits that research and development (R&D) laboratories that do work for external customers should prove their competence and that is done through well-structured and accredited quality management system. As stated before, one of the reasons for this investigation is finding a solution to the

laboratory's funding challenges. Doing more work for external clients would provide the laboratory with an opportunity to charge commercial rates for that work and subsequently creating an additional income stream.

Vermaecke (2000) also states that research laboratories that perform work for external clients must assure competence to their clients. That competence can no longer be based on institutional reputation but on a well-structured or accredited quality system. Proving competence this way can be crucial in selecting partners for research projects. A large part of the work performed by university laboratories involves collaborative projects with industry, other departments within the university and other research facilities. Having ISO accreditation would enhance the laboratory's reputation and increase the opportunities to access more of these collaborative projects.

Rauret and Compano (2003) listed the aims of implementing a formal QMS at their university laboratory. The aims were summarised as follows:

- To improve the performance and the quality of the practical work conducted.
- To improve the technical and economic management of research and teaching laboratories
- To create a culture of quality consciousness and continual improvement among staff and researchers.
- To prove competence to customers, accreditation bodies and authorities and society.

Getting ISO/IEC 17025 accreditation would greatly enhance the thin section laboratory's reputation. Most clients seek accredited laboratories to send work to and they trust the product or services they get from accredited laboratories. Clients would also have a systematic way of querying results obtained from the laboratory. The transparency offered by the quality management system would allow the organisations working with the thin section laboratory to build trust and enhance working relationships and partnerships.

De Vré (2000) stated that there is a need to respond to the change in trends in working practices and requirements for transparency. The needs are created by globalisation effects like socio-economic factors (efficiency, cost-effectiveness, client satisfaction, transparency, etc.), that place emphasis on competitive and productive scales, with the criteria being definable "indices" for objective evaluations. This further illustrates

how implementing quality management system could assist the laboratory with the challenges it is facing. The main ones being quality control and/or improvement and economic factors. Besides the need to secure additional funds to operate, the laboratory needs to optimally utilise the resources it has. Cost-effective processes need to be developed to reduce waste and the amount of expenditure associated with wastage.

2.3.2 Internal Desire and Institutional Planning

Nara (2003) state that researchers usually exchange, not only their papers but different test results with their collaborators on projects. There is, therefore, a need that those tests should be performed under the same conditions and using the same facilities to allow for fair comparisons. As mentioned before, universities survive on many collaborative projects, either with companies or with other research institutions, and it has become very important to produce results that are comparable to other institutions'. This makes it imperative that the laboratory aligns its methods to those of its partners and collaborators in research projects. The university also has plans to increase its research output, meaning that there will be an increase in the number of publications in peer-reviewed journals and that the research facilities used should also be of the required standard.

Fajgelj (2003) expressed the reasons for the implementation of a formal QMS in their faculty. Implementation was part of a much bigger project that incorporated health and safety and environmental projects. Quality management was merged with environmental care and health and safety at the work place into an Integrated Management System of Quality. This approach was utilised for a number of reasons. Some of those reasons were:

- To create the culture of quality
- To ensure that the students' teaching process is efficient and safe
- To ensure that quality management is effective

This indicates the flexibility of quality management systems. They can be integrated with other systems to create efficient organisations. The thin section laboratory is also involved in environmental initiatives while the health and safety of employees and students is a constitutional obligation. Implementing ISO/IEC 17025 would therefore

assist the laboratory with waste disposal/recycling initiatives and adherence to more stringent health and safety procedures.

Kraap (2001) states that the motivation for developing a quality approach in research and development is both scientific and economic. Self-evaluation and the implementation of improvement initiatives as a result of applying quality elements lead to enhanced scientific competence which can be exploited for various gains and the value of the research can be maximised. A quality approach in research and development can be used as a bargaining tool for gaining third-party funding. Securing funding then becomes another driving force behind the introduction of quality management systems in the research and development environment. The thin section laboratory has witnessed a downward turn in funding sources which has led to high competition for the available funding. Implementing ISO/IEC 17025 would give the laboratory an edge when it comes to funding requisitions as the laboratory might be able to offer a percentage contribution and reduce the amount it requires from the funding source. Being able to fund equipment needs will also mean that the thin section laboratory can keep up with technological advancements in thin section preparation equipment which can only enhance processes and improve the quality of the work produced.

2.4 Selecting an Appropriate Quality Management System

Rauret et al. (2003) stated that choosing the most suitable quality model for the institution is one of the first and important steps in establishing a quality management system. Bearing in mind that the challenges of the thin section laboratory are different to those of normal testing laboratories, a QMS that would encompass all the laboratory's functions would have to be identified. The thin section laboratory has to balance teaching and research work while creating the opportunity to process external request for financial reasons.

Grochau et al. (2012) listed: (1) the organisation's culture with regards to quality; (2) Examine the actual need for pursuing QMS implementation and accreditation; (3) Determine whether there are enough resources available; (4) the organisation's personnel's knowledge and experience with quality; and (5) the existing conditions of the laboratory using compliance to the standard as a reference as some of the things that need consideration before making the decision of implementing a formal QMS at

a university laboratory. The fifth point, in those listed above, is the most critical for the thin section laboratory and it is one of the objectives of this study. It entails investigating current processes and assessing the amount of changes that would be required in order to try and comply with ISO/IEC 17025:2005 requirements. It will also assist the laboratory in deciding if ISO/IEC 17025:2005 is the right standard to conform to. It also worth noting that not all clauses of the ISO/IEC 17025:2005 standard requirements would be applicable to the thin section laboratory so there is a need to thoroughly assess the clauses and their applicability to this type of laboratory.

In the standard document, ISO/IEC 17025 is defined as the standard that; specifies the requirements for the competence to carry out tests and/or calibrations. Its applicability extends to calibration and testing performed using laboratory developed methods in addition to standard and non-standard methods. It is applicable to all organisations performing tests and/or calibrations including first-, second- and third-party laboratories, and laboratories where testing and/or calibration forms part of inspection and product certification. The thin section laboratory performs many non-standard and laboratory-developed methods as it is the nature with most research laboratories. The thin section laboratory, therefore, has to choose an ISO standard that covers most of its applications and methods. Most of the methods and work done at the thin section laboratory is covered by the ISO/IEC 17025 standard which makes it the right choice of standard.

Vlachos, Michail and Sotiropoulou (2002) state that complying with ISO/IEC 17025 standard means also operating within the ISO 9001 guidelines, since they both contain many similar requirements with ISO/IEC 17025 more related to the nature and scope of testing laboratories. There are different types of quality management systems available, but ISO/IEC 17025 requirements are specifically designed for testing laboratories. That makes it a perfect fit for what the thin section laboratory intends to get accreditation for. The standard is applicable to all types of laboratories. The number of personnel or the extent of the scope of testing and/or calibration activities do not hinder the applicability of the standard to testing or calibration laboratories. Laboratories can choose the clauses that apply to their scope of duties and disregard those clauses that are not applicable. ISO/IEC 17025 can be used by laboratories to develop their quality management system, administrative and technical operations.

Laboratory stakeholders, regulatory authorities and accreditation bodies can also use to assess the competence of the laboratory.

The International Standard, ISO/IEC 17025, requires that laboratories establish, implement and maintain a quality system that encompasses the scope of the laboratories' activities. For this type of laboratory ISO/IEC 17025 is the right standard to use since most of the work that is processed is sample preparation for different tests and analysis and is not measured against any known standards and ISO/IEC 17025 makes provisions for the use of non-standard and laboratory developed procedures.

Rauret et al. (2003) critiqued ISO/IEC 17025:2005 implementation and posited that ISO/IEC 17025 is specifically addressed to the quality management and the technical competence of testing laboratories, it is developed for professional laboratories, and may not be an appropriate model for teaching laboratories. Professional laboratories carry out correct processes and to produce valid results while good teaching laboratories can use defective results or processes to enhance the process of teaching and learning. The standard is flexible and can be adapted to suit a teaching laboratory. Implementing ISO/IEC 17025 would compel the thin section laboratory to review and standardise its methods and procedures which allows for the detection of defective products and causes of defects. These can still be used in the teaching and learning process to explain cause and effect relationships in the production processes. Also, it has since been proven that there is scope for ISO/IEC 17025 implementation in university research laboratories and that the standard can be adapted to fit the functions of a teaching/research laboratory. There are examples of university laboratories that have successfully implemented ISO/IEC 17025. Zapata-Garcia et al. (2007), Rodima, Vilbaste, Saks, Jakobson, Koort, Pihl, Sooväli, Jalukse, Traks, and Virro (2005) are just some of those examples.

2.5 Benefits of Implementing Quality Management Systems.

Implementing a formal QMS has different benefits for different laboratory environments. Some of these benefits are specific to the type of organisation and their needs and some are inherent with quality management systems implementation. The best way to evaluate these benefits is measuring them up against the implementation reasons. Rodima et al. (2005) listed the benefits they observed after the

implementation of ISO/IEC 17025 in a university's testing laboratory. The benefits mentioned were:

- A noticeable increase in the number of services and contracts awarded to the laboratory which brought the laboratory closer to the community, field laboratories and industry.
- A properly implemented quality system helps introduce "real flavour" into the modules and cultivate a culture of quality awareness in the students' minds.
- Quality systems simplify teaching quality-related Topics. Having real experience of working under a quality system makes it easier to teach the principles and operation of quality management systems.

Accepting and processing work for clients from outside the university helps build relationships with people from other industries. This is significant because universities thrive on industry relationships especially for student funding/post graduate projects. It would also assist with demonstrating to students the importance of using correct sampling techniques to produce the best results. The student technicians would also get the experience of working with and solving real problems of the laboratory. Participating in the functions of the laboratory with rigorously scrutinised contracts in an environment of a real quality management system is a good experience and adds to their competitiveness in the labour market.

Hullihen et al. (2009) documented experience with implementing QMS at a university laboratory and expressed that one of the primary benefits of implementing a QMS was having documented procedures because that isolated the institution from a knowledge discontinuity if a trained or knowledgeable member leaves the laboratory. It also created uniformity as everyone would perform the same test in the same way and training methods are standardised. This would provide the laboratory with blue prints of operation and experimental methods. It would also simplify the training of new laboratory personnel and make it more organised. All laboratory personnel would be trained in the same way and their competence can easily be assessed.

2.5.1 Operational Benefits

Some of the QMS implementation benefits are inherent with the implementation of such a system and may not necessarily apply to the laboratory but can be observed

organisation-wide. Having a superior product or service affords organisations opportunity to attract and keep customers (Fasset, 2006). Organisations derive many benefits from the implementation a quality management system. Benefits such as:

- defining and conveying provider quality objectives and policies.
- facilitating uniformity in practice
- reducing, eliminating and preventing quality deficiencies
- facilitating training and competence assessment of new employees
- enabling the interchange of personnel between various tasks and responsibilities
- providing a basis for audits to be conducted and making assurances to clients

are just some of the listed ones. Having better quality thin sections produced from the laboratory would give the researchers that make use of them confidence in the data and analyses conducted on them which would greatly improve the reputation and image of the laboratory. The implementation of ISO/IEC 17025 would bring about more organisation and structure to the laboratory. It would also bring about systematic and methodical operation of instruments and conduction of experiments.

Implementing ISO/IEC 17025:2005 leads to an improvement in operational performance. A study by Halvey (2003) used the following parameters to measure operational performance from laboratories that had implemented ISO/IEC 17025:2005:

- Fewer errors and requests for reworks;
- Fewer customer complaints;
- Improved workers' skills and fluidity of workers in the laboratory;
- Improved equipment availability and reliability;
- Verification of the reliability of findings and test results.

Halvey (2003) further stated that improved workers' skills and equipment availability and reliability were the two most observed operational benefits achieved through ISO/IEC 17025:2005 implementation. The reasons and advantages of introducing quality management in research and development, expressed were; (1) allowing the comparison of results from different institutions, (2) securing public and private funding, and (3) demonstrating competence and honesty through a transparent system which

leads to credibility. Working with a well-structured QMS would aid the laboratory with assuring the quality and integrity of the work produced.

2.5.2 Business Benefits

Fernandez et al. (2006) emphasised the effectiveness of the quality system implemented and stated that an increasing number of samples were analysed, results were released on time and customers were satisfied with the services provided after it was implemented. The implementation also changed the staff's perception as they felt that the introduction of the quality system had produced positive outcomes and also allowed for the expansion of the laboratory's activities. The thin section laboratory stands to benefit greatly from improved efficiency and productivity resulting from implementing a ISO/IEC 17025:2005. The type of efficiency that can be achieved through implementing a well-structured QMS would provide the thin section laboratory with the necessary balance it needs when processing teaching and research samples.

Hullihen et al. (2009) stated that having students work on a quality system, and gain hands on experience of working in a laboratory with an ISO/IEC 17025:2005 program is different from just doing theoretical work in a quality course. This is one of the significant non-financial benefits teaching laboratories stand to gain from implementing a formal QMS; the assurance that even if the anticipated economic growth does not occur, the quality system implementation would still be worth the time and effort. The university environment compels laboratories to do more than just produce results. More time is dedicated to teaching and training. As demonstrated by the statement above, QMS implementation offers laboratories the opportunity to train student technicians in quality control, a theoretical module most of them do have in their studies.

Having a well-designed and implemented QMS, would help the laboratory create the infrastructure and environment that would enable the provision of accurate, reliable and quality service. Literary evidence suggests that this will lead to an increase in clients' and stakeholders' confidence, reduce customer complaints, ensure a more efficient process and production of quality products.

2.6 Limitations of a Formal QMS Implementation in Research/Testing Laboratories

Research laboratories are usually also involved in other routine analyses and teaching. Coordinating these duties sometimes introduces an additional difficulty in quality system implementation. Valcarcel and Rios (2003) state that QMS implementation success can only be achieved when a laboratory quality system manages to successfully merge different aims, targets, external bodies and internal assessments. This is why a thorough gap analysis needed to be conducted. There have been successful implementations of ISO/IEC 17025:2005 at university laboratories and most speak about the positive implications of the implementation to their laboratory functions. For the implementation to be a deemed a success, the thin section laboratory needs to ensure that all the stakeholders would benefit from the implementation. It cannot be that there is too much concentration on the commercial benefits of implementing ISO/IEC 17025:2005 and ignore the primary functions of the laboratory and the obligation to the teaching and learning process.

De Vre (1999) posited that some difficulties for implementing a quality management system in research and development arose from the limitations imposed by the normative approach of standards. Their rigid nature of requirements made it hard to have method flexibility inherent to research laboratories. Minor deviations from the prescribed procedures could lead to it being regarded as noncompliance. Some of the thin section laboratory's successes stem from its flexibility to adapt sample preparation methods to suit each researchers' requirements. Implementing a quality management system might limit that flexibility which will be to the laboratory's disadvantage. The ISO/IEC 17025 standard does make provisions for the utilisation of non-standard and laboratory-developed methods. It also has guidelines on how to ensure that those methods are regulated and comply with the requirements.

2.6.1 Time Constraints

Implementing a quality management system requires a lot of time and resources. For Vajda, Balla, Molnar and Bodisz (2006), the process took about five years. That includes all the stages from orientation to formal accreditation. De-Vre (2000) states that research, in its nature, is a continuously evolving process which can vary and change in form and approach over a period of time. There can be unexpected results, unpredictable occurrences and fascinating questions that arise during the course of a

research project that would require further exploration. That more often than not leads to difficulties in fixing the targets, and to stick with the pre-approved schedules and resources. It would be very challenging for the laboratory to implement ISO/IEC 17025:2005 because the nature of the work processed in the lab is very flexible and requires constant deviation from set procedures. There would also be the challenge of balancing the day-to-day activities of the laboratory, the tests and ISO/IEC 17025:2005 implementation requirements. The thin section laboratory would need to continue producing samples while finding ways to implement the quality management system. Reasonable and achievable targets would need to be set taking into account all the critical factors that influence the length of the implementation process.

Explaining how much time and resources implementation planning or preparation takes, Halvey (2003) cited cumbersome documentation among other time-consuming activities as one of the major difficulties in the process of building the quality system. Abdel-Fatah (2011) also stated that there are many time-consuming activities involved in implementing a quality system including increased documentation and system bureaucracy which can contribute to labour intensification and a decrease in job satisfaction for some staff. Vlachos et al. (2002) expressed encountering similar challenges and stated the drawbacks in the process of implementing and maintaining a quality system. Amongst those is the time-consuming and gruelling preparation to implement that can be partly caused by the laboratories' inexperience with such systems. The thin section laboratory can learn from the stated experiences of others and anticipate the possible limitations better. Possible solutions to the anticipated challenges can be devised to ensure a smoother transition to ISO/IEC 17025.

2.6.2 Financial Commitments

Abdel-Fatah (2011) counted financial constraints as one of the major drawbacks of implementing a quality management system. That stems from the high cost of building the system, calibrating the equipment, complying with environmental conditions, staff training, updating standards, etc. The cost of ISO certification which varies with the manufacturing operation and quality control practices can be another deterrent (Anderson, Dally and Johnson,1999). The application of a quality assurance system requires a great deal of commitment in human resources, company-wide effort, expertise and expenses. The system also has a tendency of bringing with it increased bureaucracy (Vlachos et al., 2002). The thin section laboratory would have to evaluate

the resources at its disposal and determine if they have enough to undertake implementation.

Hullihen et al. (2002) lamented the long-term commitment of financial and personnel resources to a quality system but also stated that while certification may be too expensive to consider for most university organisations, experience also indicates that there are heavy costs associated with running a lab that is compliant, but not certified. The sources of escalating costs are; instrument calibration, sourcing certified reference materials and providing staff with the necessary training. The thin section laboratory would have to develop the competence to calibrate equipment to the extent possible and that would require time, skill, and training.

Quality management systems require more resources to implement. From upgrading laboratory equipment and conditions, training personnel on quality to utilising the human capital equally for both the day-to-day activities of the laboratory and ISO/IEC 17025 testing. The laboratory would need to ensure that the resources for implementation are made available and spread evenly to ensure that day-today activities of the laboratory are not adversely affected by ISO/IEC 17025 implementation.

2.7 Contrasting Implementation Drawbacks Against Implementation Benefits

Abdel-Fatah (2011) posits that the implementation of ISO 17025 should be a well prepared for process. The process can have high costs but it also brings big benefits. A careful assessment of the balance between costs and benefits should be conducted and documented. Laboratories should not pursue ISO accreditation unless the anticipated benefits will be significant enough to counter the costs of establishing the system. Vlachos et al. (2002) assessed both the benefits and the difficulties of implementation and concluded that the implementation of a suitable quality system is of vital importance to testing laboratories even though the laboratories are not obligated to. Proper analysis of whether the benefits of implementing such a system will benefit the laboratory will have to be conducted by the thin section laboratory before any decision is taken.

Hullihen et al. (2009) also stated that even with the escalating costs and time consuming activities, establishing a quality system at a university laboratory has great advantages and suggested that other universities should consider implementing

quality systems. University laboratories that have undertaken formal QMS implementation and ISO accreditation processes believe that the benefits of implementing such a system are greater than any of the challenges they encountered. They have also documented ways of overcoming some of the most prevalent challenges with the implementation process. All this would assist the thin section laboratory in assessing its own readiness to implement ISO/IEC 17025:2005 should it deem it necessary and viable.

2.8 Conclusion

This chapter revealed various experiences of quality management systems implementation and ISO accreditation available in literature. It exposed the reasons why different types laboratories need to implement a formal quality management system, the benefits and challenges of implementation. Some laboratories' reasons for implementing ISO/IEC 17025 match the reasons that motivate the thin section laboratory to investigate the implementation of ISO/IEC 17025. The stated challenges would assist the laboratory in understanding what to anticipate and to devise possible solutions for those challenges. What is also important is that there are precedents by laboratories in a similar type of setting and with challenges congruent with the thin section laboratory. Those laboratories provide the necessary how-to guidelines on implementation and also provide solutions to some of the challenges faced. The literature reviewed would assist in constructing the rest of the research as some documented experiences have revealed challenges that need to be anticipated and solved. This enabled the selection of appropriate research methods and experiments which are documented in the next chapter.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter documents how this study was conducted, that is, methods of data collection, analysis procedures as well as materials and equipment that were utilised. An outline of the plans and measures put in place to ensure that the study met its credibility and validity requirements is also stated. Amaratunga, Baldry, Sarshar and Newton (2002) defined research as a process of enquiry and investigation that is systematic and methodically designed to produce answers to certain questions or solutions to certain problems and to increase knowledge. In this study, solutions to certain laboratory challenges were being sought which influenced the systematic and methodological plans outlined here. It is envisaged that being able to use ISO/IEC 17025:2005 implementation to solve the thin section laboratory's financial and operational challenges can then expose other university research and teaching facilities to the possibility of generating additional income using techniques employed in the private research/testing facilities. Identifying quality management systems' shortfalls and benefits for teaching and research laboratories will add to the existing body of knowledge and help create new contexts in which quality management systems can be deployed. In trying to come up with the best study design, literature guidelines and laboratory staff's inputs were utilised. In literature there are documented guidelines on how to conduct an effective gap analysis while the thin section laboratory personnel know the laboratory's challenges first hand. The aim was to try and investigate a possible solution to the thin section laboratory's quality, service and funding challenges using both internally available and externally sourced expertise.

3.2 Research Philosophy

Remenyi, Williams, Money and Swartz (1998) state that there has been a debate that philosophers of science and methodologists have been involved in about how best to conduct research. It has been centred on the value of two fundamentally divergent paradigms, the positivist and the phenomenological approaches. Amaratunga et al. (2002) define logical positivism as a paradigm that uses experimental and quantitative techniques to test hypothetical deductive generalizations and in contrast, the phenomenological approach uses naturalistic and qualitative techniques to understand human experience. The phenomenological approach attempts to seek understanding

and explanation of a phenomenon and not search for its external causes. This study adopted a positivist paradigm but also employed interpretivist methods in an effort to conduct the research in the best way possible. Logical positivist paradigm was deployed in the sense that the researcher utilised quantitative (survey and questionnaire) and experimental methods while interpretivist paradigm enabled the utilisation of in-depth interviews to gain further insights into the phenomenon being studied. A combination of both philosophies was deemed to be the best approach to obtain the best possible outcomes.

3.3 Research Approach

Karami et al. (2006) state that qualitative research assists in providing insights and understanding to the setting of the problem, whereas quantitative techniques bring about widely accepted methods for establishing reliability and validity of studies. The right balance between qualitative and quantitative techniques is therefore required. Deploying quantitative research, in an academic environment where there are limited resources, can enable the collection of large scale data and analysis at reasonable costs as well as the provision of statistical proof (Amaratunga et al., 2002). Quantitative research may be strong in measuring variables but it fails to provide understanding to deeper underlying meanings of cases. Qualitative data's emphasis on individual's lived experiences are well suited to provide understanding of meanings people place on events and certain courses of their lives. An effort to better understand the strengths and weaknesses of both these approaches was critical in making the decision on which approach best fitted the study being conducted.

Amaratunga et al. (2002) state that qualitative data are very useful in supplementing, validating and providing explanations for quantitative data collected from the same setting. It is for this reason that a decision to mix the two approaches instead of one was taken. Mixing the two approaches would allow for flexibility in the treatment of the data. Data sets can be used to supplement or explain further what one data set falls short at. These two approaches were combined/ mixed as an attempt to minimise the weaknesses of both and combine their strengths. Richards and Richards (1994) state the disadvantages of the qualitative approach are the complex analysis processes, large volumes of data, data classification procedures and lack of flexibility while

(Amaratunga et al., 2002) expresses that quantitative methods' short falls as its inability to provide deeper meanings to phenomena and that quantitative methods' take a "snapshot" of situations and measure variables at a specific moment and not explain those variables' wider effects on phenomena. Mixing the two approaches meant that qualitative tools, like interviews, can be used to get in depth analysis and understanding of questionnaire data instead of large samples for statistical representation while literature and questionnaire data can be used to simplify the often complex classification of interview data. In that way, the stated methodological weaknesses of both approaches were reduced.

3.4 Research Methodology

Remenyi et al. (1998) define research methodology as the procedural framework within which research is conducted including the many factors that should be considered when the choice for appropriate research methodology is made. The research topic and the primary research questions provide the basis of how the research will be conducted. This study adopted a mixed research approach with both non-sequential and sequential data collections. The survey and cause analysis results were what informed the laboratory of what experiments to conduct which made the data collection from these two sequential. Alternations between qualitative and quantitative methods also occurred due to the fact some interview follow up questions were altered after some questionnaires were returned and more knowledge of the subject was extracted from them. Johnson et al. (2004) define mixed methods research as the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study. It is also an attempt to legitimately employ multiple techniques in an effort to provide answers to research questions and not constrain researchers to a single method or technique. Mixing the two approaches also allowed for flexibility in how best to answer research questions. It enabled the selection of any approach, between the two, that would best answer the research questions and fulfil the research objectives.

Taking into consideration that different data collection methods were utilised, the best way to handle and analyse each data set had to be found. The mixed methods approach enabled the use of the best fitting method of analysis instead of trying to

follow one approach and trying to fit the collected data into one pre-selected approach. Johnson et al. (2003) provide a framework of how to effectively conduct mixed research, stating that researchers need to consider the relevant characteristics of both quantitative and qualitative research and understand the strength and weaknesses of both techniques. Once that is achieved, it allows researchers to implement the fundamental principle of mixed research. This principle, by (Johnson et al., 2003) states that researchers should collect multiple data using different strategies, approaches, and methods in such a way that the resulting mixture or combination is likely to result in complementary strengths and non-overlapping weaknesses. This study attempted to conform to this principle in both the data collection and data analysis processes.

Johnson et al. (2003) further defined mixed methods research as the type of research in which a researcher or team of researchers integrates the elements of both qualitative and quantitative research approaches in order to gain in-depth understanding and corroboration. In this study both quantitative and qualitative data collection and data analysis techniques were utilised and integrated in trying to explain the findings and extract meaning from them. Hoshmand (2003) also posits that research approaches must be mixed in a way that would provide opportunities for research questions to be adequately answered. Effectively utilising the fundamental principle of mixed research provides justification for mixed methods research. The end product will have some superiority over mono-method studies. For example, in this study, qualitative interviews supplemented the questionnaires as a form manipulation check and as a way to discuss the issue being investigated and get an understanding of participants' perspectives which will help the laboratory avoid repeating the mistakes those organisations made.

This study was based on one particular case and the findings are related to the case that was being studied although they can be used for other studies with a similar setting. As defined by (Amaratunga and Daldry, 2000), a case study is a research strategy which focuses on understanding the dynamics and factors affecting a phenomenon within a single setting. It usually refers to more intense analysis of a single instance of a phenomenon being investigated. Hartley (1994) states that case studies are heterogeneous activities that encompass a range of research methods and

techniques and differing lengths and levels of involvement in organisational function with the key feature not being the method or data understanding but the processes as they happen in particular contexts. Case studies allow for people interviews or studying documents to gain more insights into certain behaviour and enable the discovery of unique features and common traits identified in all persons within a given classification. This provided justification for the type of sampling employed and the type of data that would be extracted from the respondents as in-depth understanding of the particular case and setting is sought form them. The thin section laboratory personnel and clients provided insights into the laboratory's challenges and the questionnaire and interview respondents provided insights on what implementing ISO/IEC 17025:2005 can do for laboratories. The latter would, in theory, give the thin section laboratory an indication of what the requirements are and whether implementing ISO/IEC 17025:2005 could solve the challenges they are faced with.

3.4.1 Data Collection Instruments

Sandelowski (2000) states that combination or mixed-method studies are concretely operationalised at the shop floor level of research. The shop floor level of research is described as the level of sampling, data collection and analysis. A set of concrete operations at the technique level of research involve the combined utilisation of data collection methods that are usually associated with either qualitative or quantitative research, such as unstructured and open ended interviews and structured questionnaires. These instruments can be combined in studies to fulfil various objectives. In this study a survey, questionnaire, laboratory experiments and interviews were used to gather information relevant to the case being studied. The survey was used to gather information from laboratory personnel and clients about the observed defects in the laboratory products and investigate possible causes of those defects. Laboratory experiments, informed by the results of the survey, were conducted as a means to provide possible solutions to the product failures. Both the survey conducted and laboratory experiments were part of the internal investigations of means to simplify and streamline the processes to ensure better quality control while questionnaires and interviews were part of external processes investigating how implementing ISO/IEC 17025:2005 could provide lasting solutions to the challenges the laboratory was facing.

3.4.1.1 Interviews

Interviews were conducted with quality management systems implementation champions. In-depth accounts of their experiences with implementing the system, reasons that led to the implementation, benefits and/or disadvantages were being sought. Also included in the questions were the choice of quality management system and how that choice was made. Amaratunga, Baldry, Sarshar and Newton (2007) posit that getting expert accounts of a particular case or phenomenon makes understanding that case simpler. The qualitative data, obtained from in-depth interviews, provides well-grounded and rich descriptions of processes in identifiable contexts. It also allows for the preservation of a chronological flow of events which enables the researcher to trace that flow of events and be able to identify which event led to which consequences. Interviews are flexible, can be used in different situations and produce data of great depth. King (1994) states that the goals of a qualitative research interview are to view the topic from an interviewee's perspective and to understand the reasons why and how they came to hold that particular perspective. The decision to conduct in-depth interviews was based on the guidelines found in (King, 1994), which lists the circumstances in which a research interview is best suited. Those circumstances are as follows;

- A study that focuses on finding the meaning of a specific phenomenon to a group of participants
- Perceptions of an individual of processes within a prospective study unit
- Different individual's historical accounts describing how a particular phenomenon developed
- When exploratory studies need to be conducted before a quantitative study can be undertaken.

The third point on the list mentioned above justifies the use of interviews in this study. Personal experiences with formal quality management systems from the interviewees will give insight on various questions and challenges around its implementation.

Hennink, Hutter, and Bailey (2010) expressed that being able to identify issues from the perspective of study participants and understand their interpretations is one of the main distinctive features of qualitative research. In-depth interviews were conducted with ISO/IEC 17025:2005 practitioners who operate in environments similar to the Thin section laboratory. Attempts were made to get accredited university laboratories and

they were not successful. Commercial mineral laboratories were used as an alternative. The interviews were semi-structured with open ended questions. The interviews were conducted face-to-face and the open-ended nature of the questions allowed the interviewees a chance to explain further what their experiences were and for follow up questions to be posed. The questions covered implementation reasons, implementation strategy, benefits and disadvantages of quality management systems implementation with the aim of producing information on the case that was being studied, and to enable general conclusions, prepositions and informed assertions to be drawn. The interviews were conducted over several months and several sessions depending on the interviewees' schedules and availability. The focus was mainly on ISO/IEC 17025:2005 with other quality management systems used for reference purposes.

The interviews were designed in a manner that allowed for conversational flows. Interviews followed the structure and form of a standardised open-ended interview, described by (Gall, Gall and Borg, 1996), as extremely structured in terms of the wording of the questions. Participants were asked identical questions but those questions were phrased in such a way that the responses were open-ended allowing the participants to furnish as much detail as they desire and for the researcher to ask follow up question when necessary. Data from the interviews were collected by means of field notes as some interviewees were not comfortable with being recorded. The interview data explored the questions of choosing the suitable ISO standard, reasons for implementing a formal QMS, challenges and benefits of using such systems. Narrative analysis of the interview data was conducted.

3.4.1.2 Questionnaires

To further probe and investigate the implementation of quality management systems, a questionnaire was designed. Questionnaires are described as a tool utilised for collecting and recording information about a specific case of interest. Questionnaires are usually made up of a set of questions and include a set of instructions on how questions should be answered and provides spaces for the responses and administrative details. Amaratunga et al. (2002) state that questionnaires must always have a well-defined purpose that is tied to the research objectives. How the findings, from the questionnaire, would be used should also be clarified from the onset.

Respondents should be made aware of the purpose of the research, if possible, and should be offered to be sent feedback should they wish to receive it. Structured questionnaires are mostly associated with quantitative research and in this study they also form part of the quantitative aspect of it. Self-completion questionnaires were used in this study. Questions were e-mailed to respondents which allowed them to complete them by themselves and at their convenience.

According to Amaratunga et al. (2002), questionnaires are most commonly utilised for:

- The collection of factual information to enable the classification of people
- Gathering information relating to people's behaviour
- Seeking explanation of basic attitudes/opinions of a group of people regarding a specific case
- Measuring customer satisfaction relating to a product or service
- The collection of baseline information which will be tracked over time to analyse any changes.

The third point in the questionnaire uses listed above is what justifies the use of the questionnaire in this study. The questionnaire was used to obtain people's opinions and perceptions on QMS implementation and maintenance. The questionnaire was standardised in its design to ensure that the respondents respond to the same set of questions. It was divided into three sections, namely, Section A: Background Information, Section B: QMS implementation and the respondent's role in it and Section C: Advantages and disadvantages of having a formal quality management system. It had frequencies in addition to comparative and rating scales.

The questionnaire was administered to individuals in identified laboratories that have ISO accreditation. The laboratories used were the same ones where the interviewed quality practitioners operated. Most of the questionnaires were e-mailed to the respondents with some of them hand-distributed to the respondents. The questionnaire sought to gauge the respondents understanding of the processes that led to formally implementing a quality management system, their involvement in the implementation process and what their experiences were with prior to, during and post implementation. Guidelines on who must respond to the questionnaire were established to ensure the integrity of the data collected.

Both the interviews and questionnaires were part of external processes which would, together with findings from internal investigations, inform the laboratory if there is scope for implementing a quality management system in the laboratory, the challenges of implementing a quality management system and the benefits that implementation brings to organisations. All those would inform the laboratory if ISO/IEC 17025:2005 implementation can resolve the laboratory's challenges and if the laboratory has the capacity to develop and implement a QM system to further explore the benefits it brings. Sandelowski (2000) states that the results of some of the instruments can point researchers precisely to the kind of respondents they envisage to recruit and the exact type of information they wish to extract from them. Instrument scores can form the basis for the choice of sampling techniques in other studies. Interview respondents and the statistical analysis expert's opinion informed the researcher's decision on the sampling method used for questionnaire respondents and questionnaire analysis. Descriptive statistics analysis of the questionnaire responses was conducted.

3.4.1.3 Survey

Amaratunga et al. (2007) state that a considerable amount of research entails seeking and getting answers to questions through conducting surveys and (Forza, 2002) posit that survey designs include all activities that precede data collection where the designer has to foresee possible short comings and challenges and also strike a balance between feasibility and rigour. The Thin Section laboratory personnel went through the samples that were sent back for repeats and identified the main complaints the samples were sent back for. The four main concerns picked up from the complaints were then added on to the sample submission form which all the lab users get upon submitting samples to the laboratory. Laboratory clients were asked to complete a quality control survey on the sample submission form by ticking the corresponding boxes regarding any defect they identified in the specimens they received. These asked whether the specimens were of the correct and uniform thickness, whether there were air bubbles in the specimen, if the specimen was plucking out, if there was any loss of specimen and if they were delivered within the agreed upon turnaround time. The survey was conducted over several months (April to September 2014) and all the sample submission forms (60) collected during that period were analysed to investigate the major issues affecting the specimens' quality.

Fellows and Lui (1997) posited that survey questions can be labour intensive on the part of respondents which may lead to low response rates. It is for that reason that no sampling was involved in the conduction of the survey. All the samples submitted to the lab were part of the survey and the whole population was used. The aim was to get as much feedback about specimen quality as possible. The number of submission forms that had the quality control survey section filled in became the sample and the total number of submission forms in that period became the population. Thirty-five (35) out of sixty (60) sample submission forms responded to the survey. Bickman and Rog (1998) posited that descriptive studies are most suitable methods for the collection of information that defines relationships and give a description of a phenomenon in its specific form. The survey was conducted prior to experiments to identify specific variables that need to be manipulated and included in the experiments. The survey measured the causes of dissatisfaction with specimen quality among laboratory users with the aim of implementing corrective and preventive action or finding ways of eradicating the problem completely. The survey was standardised in its design. Respondents were asked to tick relevant boxes in responding to questions relating to the defects they observed in their processed samples. Since the survey was attached to the sample submission form, there was no need for a background information section. The survey data was descriptively analysed.

3.4.1.4 Laboratory Experiments.

Pinsonneault and Kraemer (1993) state that laboratory experiments are conducted in controlled settings to examine and understand factors that influence a particular phenomenon. Independent variables are manipulated to observe the effects they have on dependent variables. The researcher possesses direct control on the laboratory conditions and manipulation of the independent variables but the phenomena can only be studied in that present moment. Pisonneault et al. (1993) further state that laboratory experiments are well-suited to research projects that necessitate limited and well-defined concepts and problems that include individuals or small groups, a description that fits the thin section laboratory's profile and the nature of this study.

A cause and effect diagram of the survey results was drafted. Park, Nam and Choi, 2011) describe a cause and effect diagram as a tool used for conducting thorough

analyses and displaying relationships between a specific effect and identified potential causes. Those causes are then divided and sub-divided into major and subcategories. Firstly, the effect is defined followed by the major categories of possible causes. The main issues affecting the quality of the specimens produced were identified and ranked. High priority was given to the ones that were most mentioned by survey respondents. Those problems are:

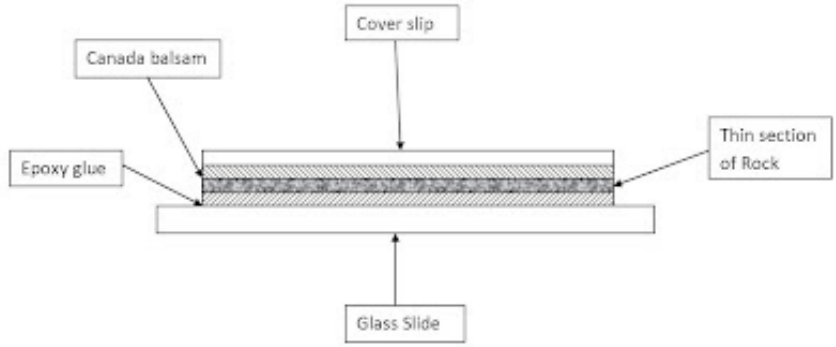
- Plucking (plucking is when grains or minerals fall off leaving holes in the thin section. This is usually observed in larger and coarse grains)
- Non-uniform thickness
- Air bubbles where the sample is mounted
- Loss of specimen

In trying to solve or minimise these problems, laboratory experiments were carried out. The aim of these experiments was to improve the sample preparation methods and eliminate possible causes of low quality specimens.

3.4.1.4a Standardising Slide Thickness

Thin sections are made by mounting a correctly sized rock sample onto a glass slide and trimming or grinding the rock mounted to the right thickness.

Figure 3.1 A Cross-Section Image of a Standard Thin Section



Source: www.kenet.co.uk

Figure 3.1 above is a cross section image of a thin section mount and the components that make the final product. The glass slides are sourced from different suppliers and the standard glass slides are usually between 1.4mm and 1.5mm thick and 26mm x

46mm length. One side of the slide is ground down (frosted) to enable easier mounting. The glass slides have varying thicknesses after frosting which made it difficult to control the quality of the final sample using measuring instruments. The possible solution to that was standardising the slide thickness to eliminate the variation it brings to the final product preparation. A single supplier of glass slides was identified, taking into consideration, prices and quality of the slides. Using the Discoplan-TS machine all the glass slides were prepared and measured to 1.3000 mm. The final thin section product is measured in the rock sample thickness. It should be 30 microns thick (0.03mm). Having standardised glass slides size means the whole specimen can be measured and the thin sectioned rock size is determined by subtracting the glass slide size from it. The experiment was conducted on 50 randomly selected samples from submitted batches. The first batch of 50 samples was mounted on glass slides with varying thicknesses and the second batch of another 50 samples was mounted on the slides with standardised thickness. The aim was to investigate if standardising glass slide thickness will lead to an improvement in the quality of the thin sections produced and lead to more uniform specimen thickness.

3.4.1.4b Pressurised Mounting

The second experiment conducted sought to solve the challenge of air bubbles formed during mounting. Air bubbles are problematic because they are the cause of plucking and can also lead to incorrect analysis as they are very visible under microscope. Different technicians use different mounting techniques depending on the nature of the samples. There is hot mounting, where the samples are placed on the hot plate at a certain temperature and there is cold mounting, where samples are prepared at room temperature. There is also pressurised and unpressurised mounting. With the different mounting techniques come various challenges. Heat helps break up the air bubbles formed during the mixing of the epoxy resin and in some cases, especially in cold mounting, the epoxy resin used can significantly increase the thickness of the thin section. Heat makes the epoxy resin less viscous and the layer of it that binds the sample to the glass slide is thinner. At room temperature the resin has a higher viscosity and results in a thicker layer. To counter this, an experiment was carried out using a different mounting technique which will work with both hot and cold mounting.

A mounting fixture was bought and all the thin section sections mounted were placed on the hot plate and pressurised until curing was complete.

Figure 3.2 A Mounting Fixture Used for Pressurised Mounting

Source: www.kemet.co.uk

Figure 3.2 above shows the fixture used for pressurised mounting. It is fitted with springs that are lifted before the sample is inserted then released to exert pressure on the sample after it has been inserted. The idea of continuously applying pressure on the samples was to try and break up any bubbles which may form, to squeeze out any excess resin and to try and keep a very thin, uniform layer of epoxy binding the sample.

3.4.2 Sampling Strategy

Suhri (2000) posits that informed decisions relating to sampling are very critical in improving the quality of research. There were multiple data collection instruments used and they all had different populations to sample from. For the interviews, the population from which the sample was drawn was quality practitioners in similar type of laboratories. Eventually, the sample ended up being people from mineral/materials testing laboratories that have implemented formal quality management systems because university laboratories that have successfully obtained ISO accreditation could not be identified. For this purpose, critical case sampling scheme was deployed. Critical case, defined by Collins, Onwuegbuzie and Jiao (2007) as a type of purposive sampling where a researcher chooses settings, individuals and groups guided by their specific characteristic(s). The inclusion of those individuals or groups bring about

compelling insight on the phenomenon being studied. Onwuegbuzie and Leech (2005) state that even though qualitative investigations usually entail the utilisation of small samples, the choice of sample size is very critical as it eventually informs the extent to which generalisations can be made. Some methodologists like Onwuegbuzie and Collins (2007), have provided a framework for sampling in qualitative studies. The framework utilises research design (e.g., case study) or research method (e.g., focus group) to recommend an appropriate sample size. The recommended sample size for case studies is a minimum of between three and five participants. Ten participants were interviewed in this study and for the interviewees; a quality management certificate/qualification was put down as a requirement in order to ensure credibility of the information collected.

Flyvbjerg (2006) posit that if the objective is to achieve the greatest possible amount of information on a specific case or phenomenon, trying to get a representative sample or even a random one may not be the best strategy. This is usually caused by the fact that a typical case does not often contain the richest in information available. Atypical or extreme cases often have a wealth of information as they usually activate more actors and more basic mechanisms in the situation studied. Random samples put emphasis on representativeness and they seldom produce a deeper kind of insight. It therefore makes more sense to pick a few cases based on the validity of the information they will provide. The use of information-oriented or case sampling is then recommended in such cases in order to maximise the utility of information from small samples and single cases. Respondents must be selected on the basis of the expected content of their information content. For the reasons stated above, non-probability or purposive sampling was utilised in this study. For the questionnaire, the population was almost similar to that of the interviews. The difference between the two was that the sample did not have to have been championing a quality management system implementation in their organisation. They could have been playing any role in the implementation process. According to Teddlie and Yu (2006), purposive sampling is defined as a form of sampling that is:

- Intended to generate a sample which seeks to address specific research questions
- To address specific purposes related to research questions
- Focus on the wealth of information generated by the cases

Purposive sampling has small sample sizes (+/- 30). The researcher selects cases where much can be learnt and understood in order to address the research questions. Stratified purposeful sampling was deployed for the questionnaires. Trost (1986) defines stratified purposeful sampling that is, from a probability sampling viewpoint, statistically non-representative but, from a purposeful sampling viewpoint, informationally representative. Each respondent represents a pre-specified combination of variables, the distinctive confluence of which is the focus of study. The sample was stratified in the sense that the respondents were at different levels of the quality system implementation and utilisation hierarchies, possess different qualifications and subsequently knowledge and practice of quality. These can impact on how they view the ease or difficulty of using the system, the importance or non-importance of its implementation and the observed benefits or disadvantages of the system. The sample size for the questionnaire was n=20.

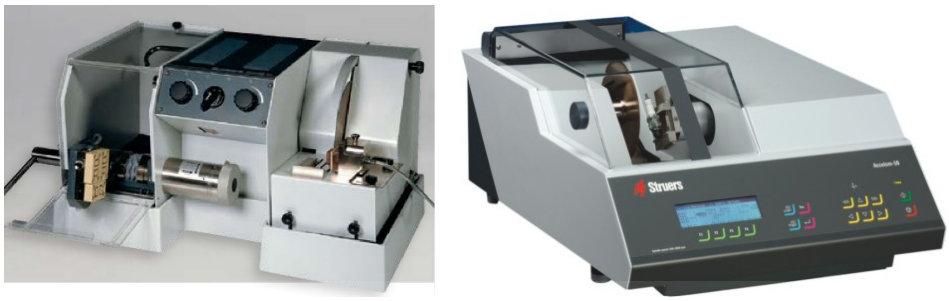
There was no intention to have a sample for the survey conducted. The nature and size of the laboratory meant that even if all sample submissions had the response to the survey, it would have still been possible to handle the data and responses. What this means is that everyone who submitted samples during the study period was part of the population. The number of responses received out of the total number of sample submissions then became the sample.

3.4.3 Materials

ISO/IEC 17025:2005 standard documents were obtained from one of the accreditation bodies. Preparation for implementation needs to be made and having the standard and following the guidelines outlined therein would make understanding the process easier. The standard stresses the need to have a documented quality system as a prerequisite for a laboratory to become accredited. A quality manual for the laboratory will need to be developed. It should outline the scope and application of the laboratory, management and technical requirements which are the two main sections of ISO/IEC 17025:2005. In accordance with ISO/IEC 17025:2005 guidelines, the laboratory will look at its management structure and assign someone who will be in-charge of overseeing implementation of ISO/IEC 17025:2005 and management of the system. It is important that the person assigned that responsibility gets all the necessary support and backing.

Two instruments used for preparation and production of thin section specimen of rocks, namely the ACUTOM-50 and the DISCO-PLAN, will be used.

Figure 3.3 A Discoplan-TS (on the left) and Accutom-50 (on the right)



Source: www.imp.co.za

These are used to prepare glass slides and to also trim and grind rocks. The lab currently uses a manual micrometer to measure slide thickness, this creates some problems because some clients use digital micrometers and the thickness obtained may differ. Also, the manual micrometer has two decimal places while the digital one has four and is more accurate. For purposes of this investigation, a digital micrometer was acquired and used. The necessary work instructions and standard operating procedures of all analytical instruments were written and handed over to the person in-charge of quality systems.

3.5 Pilot Study

Van Teijlingen and Hundley (2001) posit that pilot studies refer to feasibility studies and pre-testing of research instruments such as a questionnaires or surveys schedules. Pilot studies form a crucial part of a good study design. Though conducting pilot studies does not guarantee the success of the core study, it does increase the chances of success. They can also provide valuable insights for other researchers. Both the questionnaire and interview questions were piloted internally. Comments were sought on the structure of the interview and the ease of questions. The interview pilot study led to various different changes in the way questions were phrased and to avoid repetitive questions. The major advantages of conducting a pilot study is that it can flag problematic areas where the core research project could fall short and also give an indication on whether the proposed research methodology and instruments

would be appropriate or not. Piloting the questionnaire and interview questions allowed the researcher to fine tune them and simplify them for the respondents.

The consultation with the statistics company also assisted in structuring the questionnaire. To illustrate some of their concerns, the consultant, allowed the researcher to send the questionnaire out to five preselected respondents. Only two of those were returned. In their analysis, the consultants proposed that questionnaire be restructured. A shorter, more concise version was approved. Their advice yielded better outcomes and literature does confirm that there is a negative correlation between long questionnaires and response rates in questionnaire surveys. Van Teijlingen et al. (2001) warn that pilot studies also have limitations. These may include possibly making inaccurate assumptions and predictions based on pilot data. The pilot studies conducted by the researcher were not affected by the aforementioned limitations. Questionnaires were sent to a higher number of respondents, than the desired n=20, to try and circumvent a low response rate. The pilot studies, though sent to possible sample, were for structure and format comment and not for accurate data purposes.

3.6 Data Analysis

Johnson and Onweugbuzie (2004) state that the most common form of mixed methods studies entail using different data components, from separate data sources with different types of data or various data types from a single source, to complement or build on what might have been learned from any off those data types independently. The selection of these data is based on the understanding that they possess complementary strengths and that their weaknesses do not overlap and that a combination of them would yield stronger outcomes. Caracelli and Greene (1993) posit that qualitative and quantitative data sets can be integrated, preserving their original form or they can be transformed to create one data set by conversion of one into another. Sandelowski (2000) advises that the linking of results of qualitative and quantitative analysis techniques can be accomplished by analysing each data set with the techniques usually used with that data. That means using qualitative techniques to analyses qualitative data and quantitative techniques to analyse quantitative data. As an example, methods such as constant comparison, narrative analysis techniques, etc. should be used to analyse interview data and methods such as statistical techniques

be used for quantitative data analysis. Both sets of results can be combined at the interpretation level of the research but they remain analytically separate from each other.

The data obtained using qualitative methods, like interviews conducted for this study, was analysed qualitatively and the data from quantitative sources were analysed quantitatively. Qualitative data was deductively categorised according themes identified in literature and common themes that developed from different respondents. Although the questions, in the interviews, remained the same, the follow up questions changed after more insight was gained from questionnaire responses. This led to some of the qualitative data analysis being of an inductive nature. For the main questions in the interview, categories were created from literature, for the various responses. Data was thoroughly analysed to eliminate some categories or combine those that are fundamentally similar or added when a different type of response was identified. The most challenging part of the interviews data collection was trying to structure field notes into a coherent document which would be simpler to understand and use. Ritchie and Spencer (2002) posit that qualitative data analysis are about detection and then defining, building theories, creating categories and mapping. This was the reason why questions had to be structured in such a way that it would be simple for the participants to define the concepts the way they understood them while also giving the interviewer opportunities for follow up questions to further interrogate should the need arise. Narrative analysis of qualitative data obtained from the structured interviews were given. Using grounded theory, groups of qualitatively similar experiences were brought together in one category that had either been deduced from literature or developed from responses.

Pacitti (1998) notes that a quantitative data analysis plan usually entails assessments of raw data, recording the data, processing it, interpreting the data and communicating the findings. More often than not quantitative techniques yield data that are suitable for statistical analyses. Quoted comments can be used to enhance the communication of statistical results (Mark, Feller and Button,1997). This is another benefit of mixing research approaches. Data from interviews can be used to illustrate some points in questionnaire responses and vice versa. Also, laboratory experiments were conducted after the results of the survey conducted with laboratory clients. Results of the survey

were what led the type of experiments that were conducted and the survey identified the main problems that the experiments sought to provide solutions to. The questionnaire and survey yielded data which were suitable for statistical analysis. After the questionnaires were collected they were handed over to a statistical analyses company for further processing and analyses. Descriptive statistical analyses of the data from the questionnaires were requested. The purpose of analysing quantitative data is to provide information about variables and relations between them and statistics are very useful in determining directions of relationships when combined with theory and literature (Amaratunga et al. 2007). Survey results were also descriptively analysed to gauge how many respondents encountered the same problems and the frequency with which they encountered that problem.

3.7 Validity and Reliability

Onwegbuzie and Johnson (2006) state that the importance of validity in quantitative research was accepted a long time ago whereas in qualitative research the discussions about validity are still ongoing which has led to more terms and typologies being produced. In mixed methods research, where there is a combination of quantitative and qualitative approaches, validity discussions are in their infancy. Mixed research still grapples with the problems of representation, integration, and legitimation (Onwuegbuzie, in press). It is difficult to achieve representation when capturing or representing people's lived experiences using text, words and numbers. This difficulty is aggravated in mixed research since quantitative and qualitative methods bring representation and legitimation problems inherent in them into the setting.

Yin (1994) states that the value of any research is measured by the validity of the results it produces and the contribution it makes to the body of knowledge. Validity can be divided into internal and external validity with internal validity referring to whether or not the identified causes produce the interpreted effects and examine if the correct cause and effect relationships have been established. From the internal survey done, it was important to generate the kind of information that would help create the right cause and effect relationships. For the laboratory to be able to improve the quality of the products, the causes of dissatisfaction with the product had to be established so that preventive and/or corrective action can be implemented. Internal validity was then achieved by analysing the cause and effect diagram and confirming that the identified

causes did produce the interpreted effects. Then (1996) posit that external validation refers to the generalisability of the research findings beyond the setting in which the research was conducted and that can be achieved through forming theoretical relationships. External validity for this study will be measured by the generalisability of its findings.

It is worth noting that there is a different perspective on validity when viewed within the context of qualitative and quantitative research Onwegbuzi et al. (2006). In qualitative research it defines the absence or presence of a given feature in a given setting or situation whereas in quantitative research it measures the degree of presence of the feature. It would be difficult to ensure validity of this study using the definitions stated above as it mixes both techniques. The best way is to use both validity contexts separately. To ensure validity/credibility of this study, a lot of emphasis was placed on the sampling and data collection techniques. Guidelines on the correct or justified sampling and data handling techniques were followed and methodological triangulation was utilised as the basis for the credibility of the study.

Yin (1994) posit that reliability is the extent to which a test or procedure produces similar results under constant conditions on all occasions with the goal of minimising biases and errors in a study. The objective is to ascertain that, if someone else conducted the same investigation, using the same procedures and under the same conditions, they would reach the same findings or conclusions. Then (1996) provided the contrast between reliability and internal validity. Reliability deals with the data collection processes that ensure consistency of the results while internal validity focuses mostly on the way such results support conclusions. Validity may, at times, exclusively involve bias and from that viewpoint, validity involves systematic error and reliability involves random error (Babbie, 2001). With purposive sampling, systematic bias was to be expected. Following Then (1996) description of what reliability is and understanding that there is a need to ensure that if another investigator were to follow the same procedures the same findings would be reached, the investigator documented all the data collection procedures and used literature to justify the analysis techniques used. Anticipating that there may be different viewpoints on how best to conduct data analysis, categories for the data were derived from literature. What that did was to minimise fundamental differences in identifying the main categories when

an independent person was asked to conduct parallel analysis on the interviews so that comparative studies can be conducted to ensure reliability. There were minor disparities in fitting the responses to the categories and in creating the other categories emerging from the responses. The independent assessor agreed mostly with the analysis process. The criteria used in selecting respondents for the interviews and questionnaires went a long way in ensuring validity of this study. The respondents were experts in their field and/or had practical and hands on experience on the subject.

Although non-probability sampling was deployed for the questionnaires, statistical validity was applied. Descriptive statistics of the data would reveal standard error, variance and data skewness. These tests always reveal any biases that may invalidate the study. More method reliability tests for the laboratory thin section making procedure would be conducted. The earlier indications were that the method had stability and more variation tests were still to be conducted

3.8 Conclusion

This chapter detailed the plan for conducting the study from sampling procedures, data collection techniques and analysis methods. In addition to that, it outlined how the laboratory experiments were going to be conducted and what they sought to achieve and measures that were put in place to ensure validity and credibility of the study. The next chapter will discuss the results obtained and explain deviations, if any, from the initial plans outlined here

CHAPTER 4: STATEMENT OF RESULTS, DISCUSSION AND INTERPRETATION

4.1 Introduction

This section has the presentation of the study's results, analysis and the discussion of the study findings. Literature review and the primary data from the interviews, laboratory experiments conducted, survey and questionnaire data form the basis of the findings. The literature review conducted achieved different purposes. It assisted in providing context for the study, enabled the researcher gain more knowledge on the subject and to create categories for deductive analysis of the interview data. The analysis and interpretation of research data form major part of any research (Amaratunga et al. 2002) and as noted by Johnson and Onwuegbuzie (2004), finding the right analytical method and strategy is of utmost importance. Different types of methods like examining, categorising tabulating and or recombining data can be used to address the initial propositions of the study.

Methodological triangulation was utilised to measure the degree of confirmation or disparity between questionnaire data (n = 20) and data obtained from the interviews (n = 10). These were designed to explore the question of why and how
to implement a formal quality management system in a testing laboratory, the system's benefits and limitations for laboratories, and experiences with maintaining it. Qualitative data provided some completeness by giving contextual representation of requirements, challenges and benefits, and greater depth of understanding to the entire study. The discussion will be both deductive and inductive. The reviewed literature provided support for the developing themes and categories from the qualitative data and it assisted in developing categories for quantitative data (questionnaire).

4.2 Survey Results

The survey was the first data collection instrument used. The subsequent laboratory tests and experiments depended on the results of the survey. The survey concentrated on sample quality and the defects found in them. The way the survey was designed took into consideration that the laboratory knew there were product quality related complaints. The aim of the survey was not to identify but to show how prevalent each of the identified defects were. In that way, the causes of the most prevalent defects and their effects on the quality of the product could be identified. Only after the sources

of those defects and their effects are identified and corrective or preventive actions be applied. The survey results first showed the most prevalent defects found by lab users in their processed thin sections. From those defects a cause and effect diagram was drafted to try and identify the source of those defects which later led to laboratory experiments that were conducted to investigate corrective and preventive actions to remove those defects. This part of the study aimed to provide a response to the research question of whether there are parts of the thin section making process that can be improved to ensure better quality products. The results also provided a response to the question which asked if there is a method of standardising quality control measures in the laboratory. That was important because identifying a method of standardising quality control measures in the thin section laboratory is one of the objectives of the study.

Table 4.1 Prevalent Defects in Thin Sections

Defect	**no of complaints**	**%complaints**
Bubbles	9	25.71
Plucking	4	11.43
Non uniformity	6	17.14
Loss of specimen	4	11.43
Incorrect Thickness	12	34.29
Total number of respondents	**35**	**100**

Sixty survey forms were sent out to laboratory users after their samples were processed through the laboratory. Thirty-five (58.3%) people responded to the survey. Table 4.1 above shows how the respondents listed the observed defects on the processed thin section laboratory. From the table, it is observed that incorrect thickness is the most prevalent defect that lab users find in their samples.

Figure 4.1 Percentage Distribution of Defects.

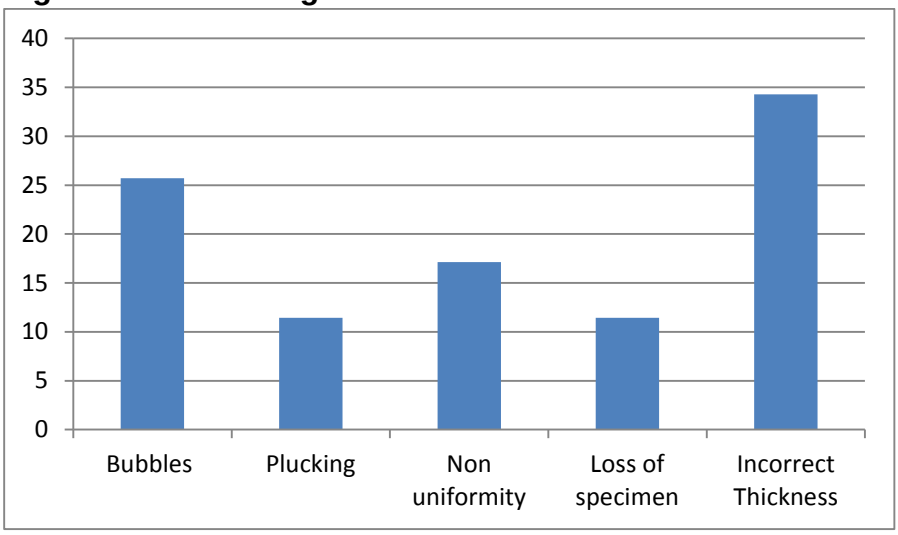


Figure 4.1 above is graphical presentation of the data presented on table 4.1. It shows the distribution of the observed defects on Thin Sections by the respondents. Thin section thickness plays an important part in properly identifying the minerals within the sample. Minerals under microscope emit different transition colours at different thicknesses. Colour matching standards are available for standard sized Thin sections (30 microns) but are not available for thicker sections. Bubbles affect the optical properties of the thin section under microscope. These are the two major defects of the thin sections, as identified by the respondents, and the laboratory had to find a way of correcting/preventing them in order to improve the quality of the Thin Sections produced. This survey was crucial in pointing the laboratory towards the type of investigations needed to come up with the necessary remedies.

Guided by the survey outcomes, a cause and effect diagram of the identified defects was drawn. The aim of drafting a cause and effect diagram was to analyse the effects of each defect on the overall quality of the Thin Sections produced. The diagram assisted lab personnel in identifying possible sources of the defects and how they affect the product quality. ISO/IEC 17025:2005:6 - Cause analysis posit that the procedure for corrective action should start with an investigation to determine the root cause(s) of the problem. Root cause analysis are the key and the most difficult aspect in the development of the corrective action procedure. At most times the root cause is not obvious and it takes very careful analysis of all potential causes of the problem to identify it. Potential causes usually include, the samples, customer specifications,

methods and procedures, staff skills and training, consumables, or equipment and its calibration.

Figure 4.2 Cause and Effect diagram of defects thin sections

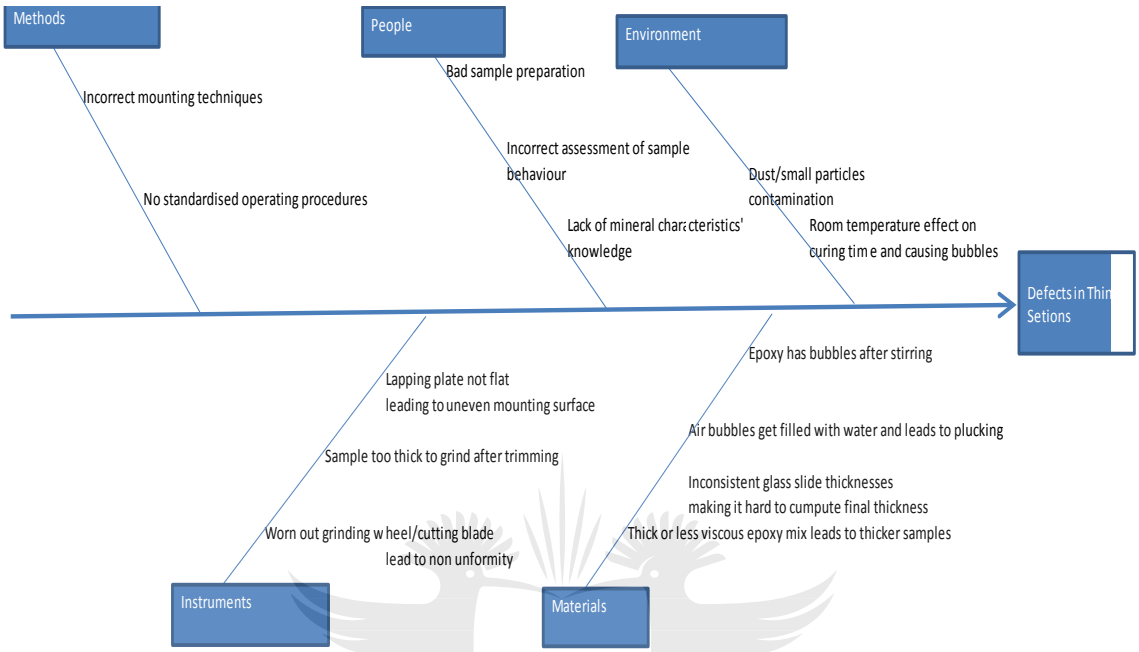


Figure 4.2 above shows a cause-and-effect diagram of what was identified as causes of defects in thin sections identified by respondents to the survey. The cause and effect diagram, also known as Ishikawa diagram, was developed in 1943 and is one of the seven basic tools of quality (Kenett, 2007). It is the flexible nature of the cause and effect diagram that makes it easier to employ in a number of different environments to extract valuable information on process failures and quality improvement projects. The thin section laboratory was able to map out the causes of defects in the product and at the same time identify possible sources of these defects. For example, the complex nature of the samples that the lab is requested to make thin sections from, led to there being no standard operating procedures in place for the thin section making process. The lab receives rocks, sand, concrete, aggregates, grains, soils, etc. which all have varying qualities and must be handled differently. It was left to the technician to assess and decide on the method of preparation. Standardising the procedure was a challenge. The solution was to write a Standard Method document for solid rocks and a separate one for treating soft rocks, loose soils, sands, aggregates and grains.

The cause and effect diagram illustrated that there may be more than one cause for certain defects and therefore a need to take a holistic approach to resolving them. The findings from the survey and the root cause analysis led to a number of changes and improvements in the Thin Section making process. An effort to standardise methods led to a selection of a single supplier for the critical consumables used in the thin section making process. This removed the variation in mixing proportions introduced by using different suppliers and helped eliminate air bubbles forming in the sample. The root cause analysis assisted the laboratory by revealing the technical aspects that needed improvement if the laboratory were to align their processes with ISO/IEC 17025:2005 requirements.

4.3 Laboratory Results

Based on the outcomes of the survey and the subsequent root cause analyses exercise, the laboratory conducted experiments in an attempt refine the sample preparation procedures and eliminate variation in the process. These experiments also sought to investigate means to eliminate the defects identified by the survey respondents.

4.3.1 Sample Thickness

The laboratory receives microscope glass slides from a supplier. The glass slides' thickness ranges between 1,400mm and 1,600 mm. The glass slides were normally hand pressed on a surface with silicon carbide powder to grind one side of the slide to enable easier mounting. That process is called frosting. It was then found out that hand pressed slides had varying and inconsistent thicknesses after frosting. The varying thicknesses of glass slides made it difficult to standardise the desired final thickness of the sample mounted on to the glass slide. To counter that, a new method of frosting glass slides was investigated. The machine, Discoplan TS, which the laboratory already had, has a function that allows the operator to pre-set the settings to desired parameters. This only required the procurement of a finer grinding wheel (80 microns) to be attached to the instrument. Samples were then prepared using the hand-pressing method and the machine preparation method. Comparative tests of the two preparation methods were carried out. Slides received from the supplier were prepared using both methods. In one batch of thirty samples, the slides were hand-pressed and frosted on one side. In another batch, they were frosted on one side, using the grinding wheel in

the machine with a pre-set thickness of +/-1,3000mm. Using a digital micrometer, the standardised slides were measured after frosting to ensure that they are as close to 1,300mm as possible.

Table 4.2 Thin Section Thicknesses of Hand-pressed Samples

Sample Names	Slide Thickness (mm)	Slide + Sample Thickness (mm)	Thin Section Thickness(mm)
BH-1	1.4577	1.5631	0.1054
BH-2	1.4573	1.5678	0.1105
BH-3	1.4737	1.4915	0.0178
BH-4	1.5183	1.5947	0.0764
BH-5	1.4387	1.4869	0.0482
BH-6	1.4199	1.6404	0.2205
BH-7	1.5026	1.7487	0.2461
BH-8	1.4411	1.6437	0.2026
BH-9	1.4509	1.5766	0.1257
BH-10	1.3827	1.5584	0.1757
BH-11	1.4756	1.5981	0.1225
BH-12	1.5223	1.6981	0.1758
BH-13	1.4196	1.5824	0.1628
BH-14	1.3774	1.4693	0.0919
BH-15	1.4953	1.5897	0.0944
BH-16	1.4677	1.5553	0.0876
BH-17	1.3199	1.4103	0.0904
BH-18	1.5309	1.6267	0.0958
BH-19	1.5157	1.7806	0.2649
BH-20	1.4436	1.5306	0.087
FT-70	1.4813	1.6344	0.1531
FT-71	1.3927	1.4301	0.0374
FT-72	1.4811	1.6014	0.1203
FT-73	1.4491	1.5586	0.1095
FT-74	1.4069	1.4485	0.0416
FT-75	1.4462	1.5158	0.0696
FT-76	1.3463	1.6643	0.318
FT-77	1.4064	1.5537	0.1473
FT-78	1.5017	1.5722	0.0705
FT-79	1.4872	1.5302	0.043

Table 4.2 above shows the results that were obtained after the first part of the experiment. The fourth column shows the calculated final sample thicknesses. Bearing in mind that the theoretical thickness of a thin section should be 30 microns plus +/-0.03mm, it was observed that besides the fact that those thicknesses didn't exhibit any precision, very few were close to the required accuracy as well.

Table 4.2.1 Descriptive Statistics of the Thicknesses of Hand Pressed Samples

Mean	0.123743
Standard Error	0.013104
Median	0.10745
Standard Deviation	0.071771
Range	0.3002
Minimum	0.0178
Maximum	0.318
Sum	3.7123
Count	30

Table 4.2.1 depicts the summary of the statistics obtained from part one of the sample thickness experiment results on Table 4.2. An average sample thickness of 0.124 mm was achieved at a standard deviation on 0.0718.

Table 4.3 Thin Section Thicknesses of Machine-prepared Glass Slides

Sample Names	Glass Slide Thickness (mm)	Sample + Glass slide thickness (mm)	Final Thickness (mm)
BH-1	1.2997	1.3398	0.0401
BH-2	1.3002	1.3418	0.0416
BH-3	1.3009	1.3416	0.0407
BH-4	1.3005	1.3427	0.0422
BH-5	1.3004	1.3409	0.0405
BH-6	1.3005	1.3421	0.0416
BH-7	1.3002	1.3387	0.0385
BH-8	1.2993	1.3399	0.0406
BH-9	1.3009	1.3422	0.0413
BH-10	1.3001	1.3407	0.0406
BH-11	1.2999	1.3411	0.0412
BH-12	1.301	1.3489	0.0479
BH-13	1.3002	1.3495	0.0493
BH-14	1.2996	1.3446	0.045
BH-15	1.2995	1.3404	0.0409
BH-16	1.2998	1.3431	0.0433
BH-17	1.3006	1.3395	0.0389
BH-18	1.2998	1.3572	0.0574
BH-19	1.3007	1.3694	0.0687
BH-20	1.2997	1.3398	0.0401
FT-70	1.2995	1.3418	0.0423
FT-71	1.2996	1.3421	0.0425
FT-72	1.3009	1.3481	0.0472
FT-73	1.2998	1.3372	0.0374
FT-74	1.2999	1.3414	0.0415
FT-75	1.2997	1.3447	0.045
FT-76	1.3004	1.3393	0.0389

Table 4.3 above depicts the result of the second part of the experiment. As it can be observed on the second column, the glass slides thicknesses are kept standard and as a result the figures on the fourth column are more precise. The desired accuracy was still not achieved but the experiment did yield positive results. It has eliminated some of the variation observed on the first set of results and which will assist in improving the quality of the final product. A comparative look at both these sets of results shows the improved precision. Technicians gave varying reasons for the amount of variation observed in the first set of results. Not being able to quantify the amount of epoxy in the final thickness was one of those reasons and an attempt to eliminate that uncertainty was made and will be dealt with later in this report.

Table 4.3.1 Descriptive Stats of the Thicknesses of Machine-prepared Glass Slides

Mean	0.043073
Standard Error	0.001156
Median	0.0413
Standard Deviation	0.006333
Range	0.0327
Minimum	0.036
Maximum	0.0687
Sum	1.2922
Count	30

Table 4.3.1 above shows the descriptive statistics of the results obtained from the second part of the sample thickness experiment results tabulated on table 4.4. What can be observed is an average sample thickness of 0.0431mm at a standard deviation of 0.0063. The reduced standard deviation illustrates the improvement in precision as this set of results is better clustered together than then previous set. The thinking behind standardising glass slides thicknesses was that it would be easier to formulate a way of computing the final thickness of the sample mounted on the slide if the glass slide thickness is known. The sample thickness can then be determined by subtracting the glass slide thickness from the total sample thickness. Using this formula: Sample Thickness = Total Thickness – Glass slide thickness. Using this formula would be a tedious exercise if the glass slides thickness is not kept standard. A technician would have to track individual glass slides thickness before doing the calculations to record the final sample thickness. If the machine is properly set up for glass slide preparation the variation in their thicknesses is greatly reduced making it easier to perform the final calculations thus saving a lot of time and increasing productivity. Standardising the glass slides led to a big reduction in variation which made calculating the final sample thickness less complicated and reduced complaints. The achieved precision points to an elimination of a major source of variation in the sample thickness computation.

To improve and streamline the specimen production method, the laboratory attempted to introduce one uniform sample preparation procedure. It was difficult to sift through all the different mounting techniques and come up with one that will be able to fit all or most of the client's needs. The results of the standardisation of glass slides removed some of the variation in final thin section thickness but also created an opportunity for

further investigations. This led to an observation that thickness added on by the epoxy layer that binds the sample onto the glass slide was unaccounted for.

The sample was bound to the glass slide by applying a small amount of epoxy onto it and then thumb-pressing it on to the glass slide. It was then placed on a hot plate (at about 50 degrees Celsius) until it completed curing. The problem with this was that different technicians used different techniques to get the sample attached to the glass slide. Some used more epoxy and others used less. Some pressed the sample harder and some did not. Also, during the root cause analyses conducted, the technicians did mention that not being able to quantify the thickness added on by the epoxy led to uncertainties in computing the final thin section thickness. All this led to varying levels of epoxy thickness and subsequently the thin section thickness. In an effort to try and reduce that variation, an experiment was designed and conducted in which equal amount of pressure would be applied on all samples. The application of pressure sought to (1) squeeze out any air bubbles that may appear when the sample is bonded to the glass slide and (2) to maintain a very thin and uniform layer of epoxy throughout the sample.

Table 4.4 Thin Section Thicknesses of Pressurised Mounting Experiment

Sample Names	Glass Slides (mm)	samples + glass slides (mm)	Sample thickness (mm)
BH1	1.3001	1.3322	0.0321
BH2	1.2998	1.3315	0.0317
BH3	1.2998	1.3325	0.0327
BH4	1.3001	1.332	0.0319
BH5	1.3003	1.3325	0.0322
BH6	1.3000	1.3312	0.0312
BH7	1.3001	1.3324	0.0323
BH8	1.3001	1.3326	0.0325
BH9	1.3002	1.3322	0.032
BH10	1.3002	1.3318	0.0316
BH11	1.3001	1.3323	0.0322
BH12	1.2997	1.3321	0.0324
BH13	1.2996	1.3317	0.0321
BH14	1.3001	1.3322	0.0321
BH15	1.3005	1.3325	0.032
BH16	1.2996	1.3319	0.0323
BH17	1.3002	1.3315	0.0313
BH18	1.3001	1.3325	0.0324
BH19	1.2997	1.3315	0.0318
BH20	1.3004	1.3322	0.0318

Table 4.4 above displays the results of the experiment conducted. The calculated sample thicknesses were the most accurate that the lab had ever achieved. Also, the amount of precision achieved from the experiment is just as important. It shows the consistency and stability of the method to produce good quality thin sections continuously. More importantly, the results allowed the laboratory to estimate the thickness of the epoxy in the thin section. From the sample thicknesses exhibited above and assuming that the sample is thickness at 0.03mm (From microscopy analysis), the epoxy thickness contribution can be estimated to be between 0.0012mm and 0.0027mm (1.2 and 2.7 microns). It is important for testing laboratories to comply with the requirements of ISO/IEC 17025:2005 regarding the estimation and reporting of uncertainty of measurement in testing as stated in ISO/IEC 17025:2005:22. Although the range of the estimation is still high, it gives the laboratory an idea of the quantity of epoxy in the thin section and eliminates the uncertainty that was there before. ISO/IEC 17025:2005:23 further posit that testing laboratories should have and apply procedures for estimating uncertainty of measurement. If, as in certain cases,

the nature of the test precludes rigorous and statistically valid calculation of uncertainty of measurement, the laboratory should attempt to identify all the components of uncertainty and make a reasonable estimation.

Figure 4.3 Line Graph of Sample Thicknesses after Pressurised Mounting

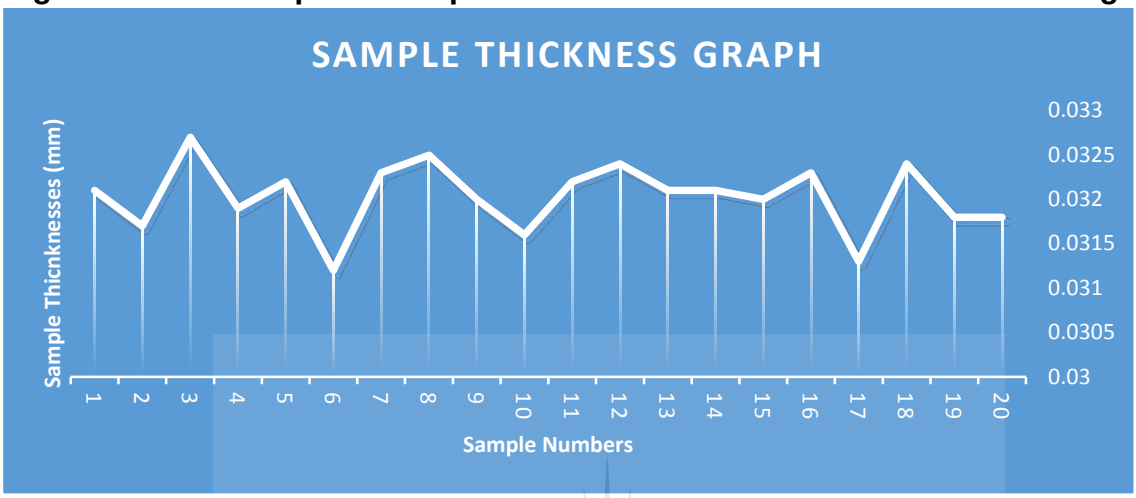


Figure 4.3 above depicts a line graph obtained from the calculated thin section thicknesses from table 4.4. Using 0.03mm as the baseline then taking the epoxy contribution into consideration, getting an average thickness of 0.03203mm was a big improvement. Also worth noting that without an accurate estimation of the epoxy thickness, a sample thickness of exactly 0.03mm was impossible to compute using thickness as a guide. What the line graph above also allows the lab is the use of it as a run chart. Each technician can evaluate whether they are using too much epoxy compared to other technicians. This will help in streamlining the method and improve the overall product.

Table 4.5 Descriptive Statistics of the Results of Pressurised Mounting

Mean	0.03203
Standard Error	8.58702E-05
Median	0.0321
Standard Deviation	0.000384023
Range	0.0015
Minimum	0.0312
Maximum	0.0327
Sum	0.6406
Count	20

A summary of the statistical analysis conducted on the results of the experiment is presented on table 4.5 above. Of particular interest is the standard deviation, the average and the median. The standard deviation proves how much precision was achieved with this method. The median was used, in this instance, because the data was skewed and did not display normal distribution. Using the median also allowed the lab to reduce the importance of any outliers observed. In the data set on table 4.5, removing the highest and the lowest values leaves a very close cluster of values. That would enable for a much more accurate estimation of the epoxy thickness in thin sections. What the calculated median of 0.0321mm informs the laboratory of is that; if the sample is 0.03mm and +/-0.002mm attributed to the amount of epoxy in the sample then a final thickness of 0.0320mm should be target. To further simplify this, the glass slide thickness could also be added and the desired final thickness of the whole section should be +/-1.3320.

What the experiments achieved was help the laboratory decipher the causes of variation in their process. The bubbles problem was resolved by the supplier that recommended heating the epoxy in mild heat, after mixing, to break up the bubbles formed. Also, pressing the sample after mounting, squeezes out and breaks out air bubbles at the same time evenly distributing the resin all over the sample. That helped the laboratory to overcome the non-uniformity challenge. Standardising glass slides and estimating the epoxy contribution resolved the incorrect thickness challenge. All the facility enhancements and experiments stated above were part of internal processes designed to improve the laboratory procedures and streamline the process to make it more effective, improve the products and bridge the gap between the laboratory processes and ISO/IEC 17025:2005 technical requirements. ISO/IEC 17025:2005 requires corrective and preventive actions and continual improvement. Implementation of such would build on from what has been achieved and ensure that opportunities for improvement are always sought. Removing uncertainties and sources of variation from the process would lead to a reduced demand for reworks in the laboratory and optimal use of laboratory consumables which would save laboratory funds.

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4.4 Interview Results

Interviews were conducted with ten (10) quality practitioners from identified mineral testing laboratories. The qualitative interviews were designed to get answers on the following research questions:

- Is there scope for the implementation of ISO/IEC 17025 in this type of laboratory?
- How do you select the right ISO standard for the laboratory? In other words, is ISO/IEC 17025 the right standard to implement for the thin section laboratory?

The question of the scope for implementing ISO/IEC 17025 at a university laboratory was not a simple one to answer and analyse. One of the reasons for that was that the respondents might not have been familiar with the challenges faced by laboratories in a university setting. Hence the decision was made that it would not be posed as it is stated above but a couple of questions and responses and, in addition, literature references would inform the researcher if the scope for ISO/IEC 17025 implementation in the thin section laboratory setting exists.

4.4.1 Interviews Findings

4.4.1.1 Reasons for Implementing Formal Quality Management Systems

In an attempt to highlight the need and scope for implementing a formal quality management system at university or research laboratories, the question was posed to the respondents asking them to give reasons why their organisations opted to implement a formal QMS. Different laboratory environments implement quality management systems for different reasons, that is why the attempt to get respondents from an environment/setting similar to the thin section laboratory was crucial. Grochau et al. (2012) posited that the implementation of a QMS in any organization could result out of internal desire, external pressure or even institutional strategic planning. In this study the internal reasons are classified as financial and operational reasons and the external reasons stem from competition from other laboratories and from clients that insist on accreditation. Deductively, the themes that emerged from the respondents, as reasons for implementing QMS, were categorised into the following groupings: (1) Financial, (2) Operational Reasons and (3) Competitiveness. These categories were derived from literature which led to the analysis being of a deductive nature. In some instances, respondents gave more than one reason for QMS implementation. All of

those reasons were distributed into the categories stated above. The reasons furnished follow similar threads as some respondents pointed out and an independent person was given the interview notes to analyse and check if they will pick up similar themes.

4.4.1.1a Financial Reasons

Respondent 1, employed as a quality assurance officer in a mineral exploration laboratory, stated that:

"The objective of a QMS implementation is improvement. What prompts that desire to improve varies from one organisation to another. In my organisation, we had a lot of complaints and requests to re-run tests to confirm results. As a result, we put a lot of resources into trying to resolve customer complaints. This put a strain on the laboratory's finances and the implementation of ISO 17025 allowed for optimal allocation of resources which saved capital and freed up funds for other projects"

From the statement of the first respondent it can be observed that the desire for an organisation to improve can be prompted by a number of reasons. In the respondent's organisation, it was prompted by the number of customer complaints and reworks they had to deal with.

Respondent 2, employed as a regional quality manager for an international materials testing laboratory, stated that:

"For us it was about improving the quality of the services we render at the lab. The implementation took place because we knew how costly it had become not to have a transparent system in place that can back your results when they are put into question. The disputed results led to loss of clients at times and ISO 17025 implementation has assisted the organisation with systematic and transparent system of handling client queries."

The common theme between the two respondents was the improvement of services and products in order to reduce the amount of time and resources spent on reworks, and resolving customer complaints. These resources can then be directed to other functions in the laboratory which would make the laboratory more effective. The respondents organisations' reasons for wanting to improve differed slightly as the second respondent also mentioned the retention of clients as one of the main reasons

for wanting to improve. Getting and keeping clients is one of the major contributors to any organisation's financial wellbeing. Implementing quality management system assisted the above respondents' organisations with resolving certain challenges. The thin section laboratory also has financial challenges and have stated that improvement is part of their reasons for conducting this study. Although, for the laboratory's intentions, it is part of a larger vision.

4.4.1.1b Operational Reasons

The improvement theme was also observed with the response from Respondent 3, who is employed as a QC technician for a commercial laboratory that provides calibration and testing services for mines and exploration companies.

Respondent 3:

"For our laboratory, it was about continuously improving data quality and laboratory effectiveness. We were already using statistical process control measures like run charts to monitor the process but we felt that those were reactive measures as you were only able to troubleshoot once you have identified the problem within the analysis run. Implementing ISO 17025 afforded us the opportunity to put in place preventive measures and also allowed us to identify process improvement gaps. This led to an enhanced analysis process and overall effectiveness of our systems.

Respondent 3's organisation implemented ISO/IEC 17025 to improve their processes and the overall effectiveness of the process. Continuous improvement opportunities could also be identified easily by having to institute preventive actions.

There was a temptation for the researcher to categorise the above response with the financial reasons responses. After careful analysis, there was realisation that the context of the latter differs slightly. The third respondent's organisation already had a quality system in place. ISO/IEC 17025 implementation was used as a tool to identify continuous improvement opportunities and enhance the effectiveness of the operations in the laboratory. The financial benefits will be there but it did not seem like their primary reason for implementing ISO/IEC 17025 was financially based. The thin section laboratory has employed check sheets as a quality control method and there were several shortfalls identified with their use. The check sheets were seldom up-to-date and when problems were identified, there were no entries on how it was resolved

and how to prevent it from recurring. Also, there was no way of identifying product defects sources if everything was ticked off in the check sheet. ISO/IEC 17025 can provide the necessary guidance on how to overcome these challenges if the laboratory decides to implement the system and keep the use of check sheets as a supplementary quality control measure.

4.4.1.1c External Pressure and Competitiveness

Respondent 7, a quality assurer at a concrete research and testing laboratory stated that:

"We had statistical process control and check sheets as quality control measures but some clients insisted on formal accreditation so we needed a system that would complement those two measures and also allow for regulation and accreditation to keep our clients happy."

Some clients only give contracts to ISO accredited laboratories, as a result, laboratories need to get accreditation for them to be able to have access to those contracts. This is true for the thin section laboratory as part of their plans include accessing more work contracts to supplement the funding it receives from the university. The reasons for investigating the implementation of ISO 17025 for the thin section laboratory are multi-faceted. The immediate reason for looking into ISO-17025 implementation is improving the quality of the thin sections. The long term view is getting accreditation and access to new work contracts or commercialise some of the laboratory's services to create another income stream.

Respondent 3 also stated that:

"There are many laboratories that offer commercial testing services to companies and that increases the competition for contracts from exploration firms. Being ISO 17025 accredited gives you some edge over those that are not and also shows your clients that you comply to the set standards that govern all the other laboratories."

Respondent 4 stated that:

"South Africa is part of the global community. We attract many organisations from different parts of the world. Being ISO accredited permits access to international clients doing work here in SA. ISO accreditation is internationally recognised."

The university space attracts many visiting researchers and academics. As respondent 4 stated above that ISO accreditation is internationally recognised, those international

researchers would benefit immensely if the thin section laboratory was to be ISO/IEC 17025 accredited. The thin section laboratory's immediate plans to improve are congruent with the reasons for most of the respondents' organisation to implement quality management systems. Perhaps what is even more in line with the thin section laboratory's vision for investigating the implementation of ISO/IEC 17025 is what was stated by Rauret and Compano (2003) that one of the aims for implementing a quality management system in teaching laboratories is to improve the technical and economic management as well as the performance of these laboratories and the educational quality of the practical work carried out. This certainly provides the scope for quality management systems implementation in teaching and research laboratories. It also demonstrates that the improvement that is sought will not just benefit the external clients the laboratory seeks to attract but also improve the teaching and learning processes within the department.

De Vre (2000), stated that the need for a quality assurance system in research and development has become very apparent. Globalisation and socio-economic factors like transparency and cost-effectiveness, put emphasis on being competitive and competence that has measurable indices for objective evaluation, have created this need. Respondent 5, employed as an ISO Systems Coordinator for a mining company, perfectly summed up the reasons for implementing formal quality management systems for different laboratories. Having implemented ISO 9001 at manufacturing and research laboratories, the respondent stated:

"Primary laboratory functions were what drove ISO 9001 implementation at our organisation. Manufacturing and production intensive laboratories' reasons for implementation will differ to research and testing laboratories. The size of an organisation also plays a role but you will find that the reasons for implementing a quality management system are interconnected. For instance, you cannot reduce customer complaints by not improving what you are offering to customers and you cannot attract new clients if the services you offer are not of the required quality. The important thing is to combine all the reasons for implementation under one common goal"

4.4.1.2 Choosing the Appropriate Quality Management System/Standard

One of the first steps in establishing a QMS is to choose the most suitable quality model for the institution (Rauret et al. 2003). Stock of the preliminary scope of the

activities which include the laboratory's physical area, tests being performed, laboratory personnel and equipment utilised, should be taken. All the respondents had the same response to the question of choosing the correct system for their respective laboratories. The route the respondents' organisations followed was conducting a gap analysis first to evaluate the laboratory procedures and, secondly, to find the perfect fitting quality management system. The difference in the responses was how the respondents' laboratories conducted the gap analysis. The responses were then categorised into two groups. The first group was organisations that conducted their own gap analysis and the second group was organisations that outsourced it to a consultant or consulting agency.

4.4.1.3 Conducting an In-house Gap Analysis

One of the steps for implementing a formal QMS outlined by Grochau et al. (2012) is evaluating existing laboratory conditions in relation to the desired quality management standard. A survey of the laboratory's current situation and the needs to comply with the ISO/IEC 17025 standard requirements will be necessary to assess the resources to be allocated, to estimate the time required for implementation and to formulate a strategy for further work. This can be achieved by conducting the gap analysis in house as Respondent 3 and 6's organisations respectively did.

Respondent 3 stated that:

"There was a quality control system in place at our organisation and the laboratory used the organisation's overall quality system. The implementation of ISO 17025 was recommended after the quality department established that the organisation's ISO 9001 did not cover all the applications of a testing laboratory and the statistical process control method had major short comings."

Respondent 6's organisation also conducted their own gap analysis. The respondent stated that:

"Our laboratory created a position for a quality coordinator and we started implementation immediately after. The quality coordinator did all the necessary analysis and made recommendations on how we should approach ISO 17025 implementation"

The statements above show that the laboratories can conduct their own gap analysis and proceed to implementation if they have the required expertise.

4.4.1.4 Outsourcing Gap Analysis to Consultants

For laboratories that do not have quality expertise, like the thin section laboratory, the task becomes more difficult. Respondent 9 provided insight into how they conducted a gap analysis. Respondent 9 posited that:

"For a small research laboratory, like ours, it was difficult to conduct a gap study because none of us had the experience of having done it before. I had a quality management qualification but not enough experience to undertake such a big task. A decision was taken by management to employ a quality consultant who assisted us with conducting the gap analysis, choosing the appropriate QM system and trained staff on the chosen standard.

The use of external consultants was also endorsed by respondent 1.

Respondent 1:

"Errrr (short pause) the similarities between ISO 9001 and ISO 17025 were the main reason why we had to get a consultant to assist us with choosing the system more suited to our laboratory. It was difficult for us to identify the appropriate quality management system and using a consultant made all the difference"

The deployment of consultants to assist with formalising quality management systems in organisations has been documented before. Grochau et al. (2012) stated that the QMS should be developed internally, respecting the peculiarities of the laboratory and of its personnel, even with the help from external consultants. Respondent 10, who is currently employed at a university laboratory, stated:

"University laboratories usually do not have to use external consultants. Other departments could provide consulting services as they have experts in different fields employed by the university already. That was what we did when the idea of a QMS implementation was initiated. The ISO 9001 implementation served as an honours project for one of the industrial engineering students. The collaboration between departments that is usually promoted at tertiary institutions enabled the laboratory to conduct a gap study for the implementation of ISO 9001 at a lower cost than what a consultant would have charged"

The thin section laboratory's setting is both a blessing and a curse. While being in a university environment creates challenges, it also provides opportunities and resolutions to some of those challenges. Rauret et al. (2003) posit that the standard was conceived for the professional laboratories and may not be applicable to teaching laboratories. This, at first glance, seemed like a challenge until the realisation that for many years the research and teaching parts of the laboratory have always worked in tandem. The "interesting" specimen and ones that have a lot of information from research processes are always curated and used as teaching material. Implementing ISO/IEC 17025 will bring the required professionalism to the laboratory and enhance the teaching part as well. Respondent 8, who works for a calibration laboratory stated: *"ISO 17025 is better fitted for research and testing laboratories because those types of laboratories deal with uncertainties in their results and utilise many laboratory-developed procedures. The ISO/IEC 17025:2005 standard makes provisions for the validation of uncertainties and the use of non-standard methods".*

The nature of the thin section laboratory and its core functions is what determined which ISO standard would suit it. ISO/IEC 17025's applicability and application scope was found to be the best fitting one.

4.4.2 Challenges Encountered when Implementing Formal QM Systems

Formalising quality management systems in laboratories has advantages and challenges. The challenges vary with the type of laboratory and the impacts of those challenges differ from one laboratory to another. Respondents pointed out a few challenges they faced when implementing a quality management system. The challenges were either internal or external. The categories identified for internal challenges were (1) organisational culture and (2) lack of resources and the external ones were (1) Cumbersome documentation and (2) Increased bureaucracy.

4.4.2.1 Internal Challenges

a). Organisational Culture

Respondent 3 commented about lack of staff participation and added that sometimes there is resistance as well. The respondent stated that:

"In a big organisation, like ours, uhhhmm it is difficult to get people to cooperate. Most members of staff did not like the added responsibility. We also had problems with getting the required cooperation from different departments. For instance, people at the production department would not give test samples the priority we expected and we ended up sending quality team members to different departments to conduct those tests."

Ndafyaalako (2010), having implemented ISO 17025 in a small municipal laboratory, also shared respondent 3's sentiments and stated that the opinions of many staff members were that implementation of ISO 17025 is the sole responsibility of the Quality Assurance (QA) manager… first and second level of analytical staff were of the opinion that they play no part in it. The above statements demonstrate a lack of interest and participation from the rest of the staff. Undertaking a task as big as implementing a quality management system requires that everyone in the organisation participates and contributes. That would make it easier for the implementation to become a success.

It is therefore very important to brief everyone within the organisation about the plans that are being made, their roles and responsibilities and how it will take the organisation forward. As Vermaercke (2000) expressed commitment to the quality system must come from both management and employees. A bottom-up approach, good communication across all levels, a user-friendly document control system and a set that emphasises total quality ahead of quality control must be established. Organisational culture is one of those challenges that are very dependent on the nature and size of the organisation. It is difficult to imagine how mutiny can affect a very small laboratory like the thin section laboratory as it is easy to assign responsibilities and track if the responsible individuals are doing what is expected.

b). Lack of Resources

ISO/IEC 17025 implementation requires that management should commit to making the required resources available. Not having some of the necessary resources becomes a hindrance in the bid to successfully implement ISO/IEC 17025. Some of the respondents stated the resources constraints they encountered during implementation of a QMS. Those are categorised below

I. Financial Constraints

The high cost of the system is one of the major challenges of QMS implementation at university/research laboratories. Abdel-Fatah (2010) stated the various factors that influenced and escalated the costs when they undertook the ISO/IEC 17025 implementation project. Ndafyaakalo (2010) also stated that implementing ISO 17025 increased both operational and capital costs as there was a need to purchase new equipment, reference material, organise specialised training for laboratory personnel, hiring consultants, etc. Respondents also stated that implementing a QMS is a very expensive exercise. Respondent 1 stated:

"The budget can never be enough for such a huge task, management always had to make funds available for what needed to be done at any given point. There had to be some flexibility applied when it came to the budget because system requirement assessments almost always revealed major non-conformities and that led to fluctuating costs."

The gap analysis conducted should give the laboratory an idea of the resources required to implement an ISO/IEC 17025 and inform the laboratory of its viability.

II. Time Constraints

Vermaercke (2000) expressed that the whole process of accreditation is relatively long (several years) with many ups and downs, since management of change creates resistance. There are factors that contribute to the whole process ending up being a lengthy one. Amongst those is staff training as stated by respondent 9. The respondent stated that:

"Laboratory staff needed quality training. It was difficult to tell a person to change the way he had been doing things. Quality training also took some technicians off their day-to-day responsibilities which led to added pressure on the laboratory's production"

There are various factors that influence quality management system implementation time. Mann and Kehoe (1995) stated that employees who have been in the organisation longer are more likely to resist new initiatives. This can result in many difficulties and can lengthen the process of implementation. Respondent 1's statement indicates the complexity of implementing a quality management system. Offering training to staff may solve the challenge of their apathy and resistance to change but

it can also escalate costs and extend the period of implementation. Grochau et al. (2012) stated that the staff should be trained regarding the various quality related aspects (ISO/IEC 17025 standard, estimation of measurement uncertainties, and internal audits) and, when necessary, in the associated technical issues to qualify for their jobs. Especially for teaching and research institutions, where the presence of temporary staff may be considered a problem, training and supervision are fundamental. In the end, training staff is a necessity whether a formal quality system implementation happens or not. Well-trained staff benefit the organisation immensely.

4.4.2.2 External Challenges

a). Increased Bureaucracy and Cumbersome Documentation

De-Vre (2009) counted external pressure from the quality system as one of the serious constraints of implementing it. The pressure exerted by the quality system can be time consuming and demanding when it comes to developing infrastructure and getting rid of old habits, and it could also undermine scientific prestige of research groups. Accreditation bodies compels laboratories to be periodically audited, after accreditation, to ensure that they remain compliant which brings unwanted and undesirable scrutiny to the laboratory. It also means that there must be time put aside for internal and external audits which puts more pressure on laboratory personnel. The respondents commented on the amount of documentation that the system requires as it is known to require a lot of documentation and record-keeping.

Respondent 6 stated that:

"The amount of documentation that the system required were almost a deterrent and it didn't help that we had to keep records of every detail even those that we considered minor. Keeping records up to date added more work to the daily "to-do" pile and it was a struggle to reach the required targets."

Respondent 3 corroborated respondent 6' sentiments and stated that:

"Documentation was a nightmare, but we got lucky because the organisation already had a quality system and all we needed to do was to get the laboratory documents in order. ISO 9001 has many similarities to ISO 17025 and that helped circumvent many required documents. Some were just adopted from the organisation's quality system and amended to fit requirements".

This would be a bigger challenge to the thin section laboratory as there is no rigorous documentation and/or record keeping procedure. The sample submission forms were only kept for productivity tracking purposes until a quality control section was added to the form.

Respondent 9 stated that documentation was not a big challenge to them as they had the services of a quality consultant. The respondent stated that:

"The consultancy firm offered the laboratory the services of a quality administrator that handled all the documentation. Even though it escalated the cost of implementation a little, it took a lot of pressure off the rest of the staff."

Part of the reason why the thin section laboratory is investigating implementing ISO/IEC 17025 is to gauge how far off compliance is the laboratory at. Identifying the challenges that will directly affect the thin section laboratory is crucial and so is devising possible solutions to them or coming up with trade-offs that will benefit the laboratory. What the interviews have done is show that what was a problem in one organisation, another organisation had a solution for it.

4.4.3 Benefits of Implementing Formal Quality Management Systems

Implementing a quality management system has to have great benefits or laboratories would not be going through such an effort to get accreditation. Respondents were asked if they noticed any improvement in different aspects of the laboratory after the implementation of a quality management systems. Most of the stated benefits were linked to each or occurred as a result of one aspect improving. The responses were categorised as either operational or financial.

4.4.3.1 Operational Benefits

In response to the question about observed benefits after a QMS implementation, respondent 1 stated that:

"After the implementation of ISO 17025, we reduced customer complaints by about 60%. The system led to an improved analysis process and we could pick up outliers and resolve them before submitting them to the client."

This proves that without the necessary improvements in the process, respondent 1's organisation would not have been able to reduce customer complaints. Implementation of ISO/IEC 17025 enabled the organisation to diagnose and correct problems before the client could point it out to them. Respondent 8 also expressed that there was an overall improvement in the efficiency of the analysis process which led to improved products and service provision. Respondent 8 stated that:

"The quality management system helped streamline our work procedures. Unnecessary parts of the process were cut off and that led to a very efficient operating system. Our products improved and clients' queries were handled systematically."

An efficient process brings about many other benefits like reallocation of resources to other important projects and identifying continuous improvement opportunities. Respondent 9 commented on the observed benefits and stated that:

"Laboratory personnel benefitted a lot from the quality training they received. Most of them are now multi-skilled and can perform different functions within the laboratory"

Respondent 9's statement is corroborated by Halvey (2003) who posited that improved workers' skills and equipment availability and reliability were the two most observed operational benefits achieved through QMS implementation. Implementing a quality system could assist the laboratory with improving equipment utilisation and increase laboratory staff's skills matrices.

4.4.3.2 Financial Benefits

Respondent 7 stated that implementing a quality system led to fewer requests for re-analysis which freed up time and resources for other tests to be completed timeously. The financial implications of that was that the laboratory cut down its spending on consumables and enhanced its reputation by being able to stick to agreed-upon turn-around times. Implementation of a quality system can assist with reducing the defective products and eliminate the need for reworks which has great benefits. Over time, the spending on consumables escalates due to reworks and defective products. Eliminating or reducing both frees up some funds to be directed to other important laboratory functions. This, together with improved process efficiency, would assist the thin section laboratory in cutting out unnecessary spending. Most of the observed

benefits are interconnected. Improved quality products would lead to satisfied customers, less complaints and less requests for rework.

Rodima et al. (2005) posited that there was a significant increase in the number of services and contracts received, after implementing ISO/IEC 17025, which helps bridge the gap between the university and society, the university and industry and field laboratories. This removes the tag of universities being “ivory towers”, a perception about universities that is prevalent among practitioners. The system, when properly implemented, introduces “real world flavour” into quality management studies and creates/broadens the quality awareness knowledge in the minds of the students. The quality system helps in teaching quality-related subjects. It is difficult to teach principles of operation of quality systems without having real experience in working under one. One of the respondents namely, respondent 8, stated that they observed an increase in new work contracts after the implementation of a formal quality management system and subsequent accreditation. The respondent attributed that increase in work contracts to two reasons:

“There was a noticeable increase in the number of projects we received after getting ISO 17025 accreditation. I can’t say for certain why that happened but I think it could be word of mouth from satisfied clients, the fact that our client liaison team had ISO 17025 accreditation to offer prospective clients or due to the fact that the laboratory got accredited and organisations who would not normally give us projects before could give them to us after we were ISO certified”

Accessing more work contracts is part of the long term aspirations of the thin section laboratory and it is demonstrable from the stated benefits that implementing a quality management system would be a step in the right direction. Inductively and deductively analysing the data allowed the researcher to supplement the interview questions and use literature as a reference for some questions and responses. Follow up and supplementary questions were added on to the list as more information and knowledge on the subject was provided by other interviewees. This led to a better understanding of the technical issues at play and allowed for a better interpretation of the themes and categories. The smaller sample size permitted for a simpler way to categorise and group responses. Even if respondents had all given different responses to any of the questions, it would still have been possible to document each response and not group

it as an outlier. What was evident in the responses was that all the respondents supported the implementation of a formal QMS. All of the interview respondents stated that, even with the challenges they mentioned, they would still recommend implementing a structured quality management system to organisations.

4.5 Questionnaire Results

4.5.1 Introduction

It's particularly important to refer back to the original aims of your study and the hypotheses that you wish to test at this stage to keep your analysis focused (Williams, 2003). Bearing in mind the objective of the questionnaire which was to gauge the respondents understanding of the processes that led to quality management system implementation, their involvement in the implementation process and what their experiences were prior to, during and post ISO/IEC 17025 implementation, the sample was slightly different to that of the interviews. In the questionnaire, it wasn't a requirement to have been championing the implementation process. The target was people who were involved in various capacities during implementation. The information that was being extracted would assist the laboratory in determining whether any laboratory personnel would be able to interpret ISO/IEC 17025 system requirements and apply them. The questionnaire was sent to thirty-five possible respondents. The statistical analysis expert recommended a sample size of twenty (n=20) for the descriptive analysis that were going to be conducted. Twenty-five responses were received and were cut down to twenty based on comparisons of the respondents' laboratories and the Thin section laboratory. The ones with functions that closely matched the thin section laboratory's functions were given top priority. The laboratory employs many student technicians at different intervals so it was also important to probe ISO/IEC 17025 user friendliness and operational maintenance requirements. Understanding the operational requirements and how user friendly the system is would assist the researcher in determining the level of knowledge and training one needed in order to be able understand and apply the system.

The questionnaire sought to give more clarity on the questions answered by interview respondents.

- How was the quality management system selected?
- What were the reasons for implementing a formal QMS?

- What were the challenges encountered with implementation and what were the observed benefits after implementing it?

These questions would assist in clarifying the scope of implementation and what needs to be done before embarking on the implementation project. The information obtained from questionnaire would indicate how people, who are not quality experts but work with the system, think of the system's effectiveness and whether they would recommend it to other laboratories. The analysis of the questionnaire was deductive in the sense that the categories of the different questions were drafted and structured based on literature and responses from the interviews. In analysing the questionnaire responses, reference to the literature and interview responses would be made. The questionnaire had a demographics section for the respondents and also the type of laboratory they worked in. The demographics section sought to elicit from the respondents (1) their level of education, (2) the type of laboratory they work in and (3) the number of years they have worked in an ISO accredited laboratory. Descriptive analysis of the main category questions in the questionnaire will be conducted.

4.5.2 Respondents' Background Information

Table 4.4.1 Questionnaire Respondents' Education Levels

	Frequency	Percent
Grade 12 (Matric, std. 10)	1	5,0
Post-Matric Diploma or certificate	5	25,0
Baccalaureate Degree(s)	12	60,0
Post- Graduate Degree(s)	2	10,0
Total		20

Table 4.4.1 above shows that 95% of the respondents were in possession of a tertiary institution qualification. The respondents' level of education was important because it would indicate the system's user friendliness. If people across an organisation's organogram, who do not possess quality management qualifications, could be assigned responsibilities and be able to perform them in accordance with ISO/IEC 17025 system requirements, that would indicate that the system could be used by various people with various levels of education. It would also assist the thin section laboratory with identifying and assigning tasks to relevant personnel.

Table 4.4.2 Respondents' Experience with Formal QMS

Experience	No of Respondents	Percentage
1-2 years	2	10
3-5 years	7	35
6-9 years	9	45
10 years plus	2	10

Table 4.4.2 above depicts the experience levels, of questionnaire respondents, with QM systems. It must be specified that the respondents did not have to have been in charge of the implementation process. They might have been part of the team in any capacity and having different responsibilities. The interviews had already afforded the researcher the opportunity to get in depth responses from people who were championing QMS implementation. What the questionnaire would do is offer supplementary information to that of the interviews and to try and gauge how people feel about the implementation of formal QMS in their organisations and compare that to the sentiments expressed by quality practitioners in the interviews. The statistics consultant recommended that the questionnaire be administered to people who had higher qualifications and more experience working with a formal QMS because descriptive statistics were going to be conducted and they needed respondents with hands on experience. This was also done for qualitative analysis credibility purposes. The adverse effect of that is that it brought some bias as most shop-floor level respondents could have been excluded by the education or experience level requirements for the study.

Mann and Kehoe (1995) listed employees' skill levels, employees' length of employment (experience) and employees' educational levels as some of the factors that affect total quality management implementation. Highly educated and highly skilled employees are usually more receptive to change than their less educated and less skilled counterparts. The highly skilled personnel also feel less threatened by proposals of implementing changes and understand why there is a need for change. In order for an organisation to increase the autonomy of their workforce, it may need to improve its employees' skill levels. Long-serving employees are the ones more likely to resist change since they may have witnessed other management approaches which did not achieve the expected successes. That would then make some of them sceptical

to other initiatives. Respondents' education levels and experience were included in the questionnaire as a way of assessing if any of the factors stated above could have influenced the responses offered.

Table 4.4.3 Types of Laboratories Questionnaire Respondents Are Employed in

	No of responses	Percentage
A2.1 Manufacturing/Production	4	20.0%
A2.2 Calibration/Testing	11	55.0%
A2.3 Research and Development	5	25.0%

Attempts were made to get respondents from university laboratories but they proved to be unfruitful. The university laboratories contacted either did not have a quality management system in place or were also in the process of conducting feasibility studies of implementing one. As a result, mineral testing laboratories were used to get respondents. The nature and uses of thin sections allow for their utilisation across different sectors and for different applications. Rocks, concrete, sand and soil testing laboratories make use of thin sections in their various forms. Mineral Research and Development laboratories closely match what the thin section laboratory does and mineral testing and calibration laboratories are what the thin section laboratory intends to do in the future. Responses from R&D and Calibration and testing laboratory personnel would weigh more in the long term.

Table 4.4.4 Type of Formal QMS/ISO Standards Employed by Organisations

Type of Quality Management System	Responses	
	N	Percent
A3.1 Good Laboratory Practice	1	5,0%
A3.2 ISO 9001	7	35,0%
A3.3 ISO 17025	11	55,0%
A3.4 SPC	1	5,0%
Total	20	100,0%

Table 4.4.4 above shows the different ISO Standards and QM systems used in the respondents' respective laboratories. ISO 17025 being the dominant one which was to be expected based on the type of laboratories that the study targeted. It must also be observed that some organisations use more than one standard depending on their size and nature of applications. Some of the respondents work for such organisations and

from the interviews conducted with quality practitioners, the advantages and disadvantages of combined quality management systems, were expressed. Statistical process control was also mentioned as one of the quality control instruments used by the organisations. From the interview data, it was also observed that SPC and check sheets were used, more often in combination with ISO Standards or as a quality control measure in preparation for formal accreditation.

4.5.3 Role Players in Formal QMS Implementation.

Table 4.4.5 Influence of Various Role Players in Implementation

	Not influential	Slightly influential	Somewhat Influential	Very influential	Extremely influential	Total
B5.1 Project Owner	0	0	1	3	15	19
	0,0%	0,0%	5,3%	15,8%	78,9%	100,0%
B5.2 QA Manager	0	0	4	7	8	19
	0,0%	0,0%	21,1%	36,8%	42,1%	100,0%
B5.3 Senior management	0	1	3	3	12	19
	0,0%	5,3%	15,8%	15,8%	63,2%	100,0%
B5.4 QA Team	0	2	5	5	8	20
	0,0%	10,0%	25,0%	25,0%	40,0%	100,0%

Table 4.4.6 Summary Statistics of the Influence of Role Players in Implementation

	Mean	Median	Mode	Std. Deviation	Minimum	Maximum
B5.1	4,74	5,00	5	,562	3	5
B5.2	4,21	4,00	5	,787	3	5
B5.3	4,37	5,00	5	,955	2	5
B5.4	3,95	4,00	5	1,050	2	5

Table 4.4.6 depict the importance assigned to different role players in QMS implementation by respondents. What this indicated is the importance of every role player within the implementation team. It also pointed out how influential each member's contribution to achieving implementation was. The statistical analysis conducted revealed that all the role players were rated on average of four which is between influential and very influential in the scale provided to the respondents. This proved that a task of this magnitude required effort from everyone involved. Ndafyaakalo (2010) stated that some laboratory personnel leave the ISO/IEC 17025

implementation responsibilities to management or the quality manager. The questionnaire responses were in line with the statement cited above. 78.9% of the questionnaire respondents seem to certainly think that the QA manager is the most influential person as opposed to 40% who think that the whole team is influential on the successful implementation. This might also be the explanation to the challenge expressed by interview respondent 3 about organisational culture and people resisting added responsibilities.

When using the median, which has values between 4 and 5, as an indicator, it is clear that the respondents think that everyone involved in the implementation of a QMS is influential and has a role to play. As mentioned before, the thin section laboratory is relatively small in size and has a few permanently employed technicians. It would be easier to track if everyone is doing what they are supposed to do. It would not be difficult to identify anyone who is neglecting their duties. It will also be easier to get everyone involved compared to larger laboratories.

4.5.4 Reasons for Implementing Formal Quality Management Systems

The reasons, furnished by the questionnaire respondents, for QMS implementation were very similar to the responses obtained from the interviews. What the questionnaire results did was give weight to the different reasons on why many organisations implement QMS.

Table 4.4.7 Reasons for Implementing Formal QMS

	Not at all important	Slightly Important	Neutral	Moderately important	Very Important	Total
B6.1 Improving the quality of the products and services	0	1	1	2	16	20
	0.0%	5.0%	5.0%	10.0%	80.0%	100.0%
B6.2 To get accreditation and audited	0	1	0	4	14	19
	0.0%	5.3%	0.0%	21.1%	73.7%	100.0%
B6.3 To streamline processes and simplify work procedures	0	1	5	3	11	20
	0.0%	5.0%	25.0%	15.0%	55.0%	100.0%
B6.4 To reduce customer complains	0	1	1	4	14	20
	0.0%	5.0%	5.0%	20.0%	70.0%	100.0%
B6.5 To get access to more work contracts	0	0	4	2	14	20
	0.0%	0.0%	20.0%	10.0%	70.0%	100.0%

Respondents to the questionnaire mentioned access to more work as one of the main reasons for formalising quality management systems. About 70% (see table 4.4.7) of the respondents said that was a very important reason for the implementation whereas

during the interviews, none of the quality practitioners mentioned it as one of the main reasons for implementing QMS though respondent 8 did count it as one of the observed benefits. This is an indication that there could be many more hidden benefits that organisations stand to gain out of the implementation of a formal QMS other than the ones already stated. 80% of the respondents stated that improving the quality of the products and services was a very important reason for the structured QMS implementation. This was in line with the interview respondents.

Earlier discussions in this report did state that the reasons for implementing formal quality management systems differ from organisation to organisation. For the thin section laboratory, the investigation of ISO/IEC 17025 implementation is linked to improving the quality of the products and to be able to compete for industrial work to supplement the laboratory's income. If any laboratory has intentions of conducting testing for the private sector, it is important that they are able to demonstrate compliance to internationally recognised standards. As Hullihen et al. (2009) stated that there is a continuing need for industry to follow and use International Organisation for Standardisation (ISO) standards which, in turn, puts pressure on university organisations that perform laboratory testing for outside organisations, to ensure that their results satisfy the required standards of the requesting organisations.

4.5.5 Disadvantages of Implementing Formal QMS

Implementing a quality management system comes with its own challenges. Successful implementation rests on identifying these challenges and finding means of overcoming them. Respondents were asked to state the frequency of these challenges if they encountered them during implementation.

Table 4.4.8 Challenges Encountered when Implementing Formal QMS

	Never	Rarely	Occasionally	Often	Always	Total
B9.1 Cumbersome documentation	1	0	1	10	7	19
	5.3%	0.0%	5.3%	52.6%	36.8%	100.0%
B9.2 Budgetary constraints	0	2	14	2	2	20
	0.0%	10.0%	70.0%	10.0%	10.0%	100.0%
B9.4 Time constraints	0	3	6	3	7	19
	0.0%	15.8%	31.6%	15.8%	36.8%	100.0%
B9.5 Lack of staff interest/participation	1	2	10	3	3	19
	5.3%	10.5%	52.6%	15.8%	15.8%	100.0%

Using the categories obtained from the interviews and from literature, the questionnaire respondents were asked how prevalent were some challenges in their organisations when a quality system was being implemented. Displayed in table 4.4.8 above is the tabulated results of the frequencies of the stated challenges. There is a disparity between what the questionnaire respondents regarded as the major disadvantage to what the interviewees stated. Interviewees had financial challenges as their biggest disadvantage and questionnaire respondents stated that they often encountered cumbersome documentation as their biggest challenge. That is understandable because project owners, like quality assurance managers, etc., would know more about budgetary limitations than any other team members. The information would then filter down to the rest of the organisation if management were not able to find solutions to the financial challenges, that might explain the increased percentage in the "occasionally" column for budgetary constraints. Also, the interviewees stated that they encountered more staff resistance while the questionnaire respondents said they occasionally encountered staff resistance. The explanation for that maybe what Ndafyaakalo (2010) observed, that the laboratory personnel thought that quality implementation was the responsibility of the quality manager and not everyone. More often than not, people tend to shy away from responsibility so that they would not be blamed when projects fail. Also, resistance would be observed more by people at the forefront of the project rather than team members.

It is understandable that questionnaire respondents identified time constraints as one of the major challenges of implementing formal quality management systems. 52.2% of the respondents stated that they often and very often encountered time challenges. Vajda et al. (2006) stated that implementing a quality management system can take up to several years. The process from the orientation stage to formal accreditation took about five years for some laboratories. If one considers that implementation generally takes place simultaneously with the normal work/production process, which leads to shop floor level operators having to do extra work/tests to enable smooth transition to the new system. There is also the challenge of coordinating various functions within the process to make sure that the tasks are aligned. Respondents to the questionnaires expressed that the amount of documentation required for formal quality management systems was a major challenge. The ISO/IEC 17025:2005 standard document requires that records be kept for archiving, tracking and auditing purposes. What the researcher

gathered from the interview responses was that the initial drafting and amending of documents is the tedious part of the documentation process. Once the documents and records are stored, it is not as tedious a task to update them if and when it is required.

Some of the challenges mentioned above would not apply to the type of laboratory the thin section laboratory is. Perhaps the challenges that could directly affect the thin section laboratory's plans to implement ISO/IEC 17025 are the ones stated by Grochau et al. (2012): (1) the provision of testing services is usually not a priority; (2) high laboratory staff turnover; (3) the laboratories are shared with the research and teaching activities; (4) the staff's functions and responsibilities are varied and diffuse; and (5) performance is measured on the basis of the amount of material produced for teaching activities and publications. The financial challenges that the thin section laboratory is facing has made the provision of testing services a priority. Measures to ensure that implementation is approached in a way that benefits the testing, research and teaching activities of the laboratory need to be put in place. The laboratory also utilises student technicians instead of temporary staff, they get to earn an income while concluding their projects. Working in an ISO accredited laboratory would enhance their career prospects. The staff's function and responsibilities being varied and diffusing is as much a limitation as it is a benefit for research and teaching laboratories. The laboratory performs many non-standard procedures that clients sometimes request and having various laboratory personnel being trained and competent to perform multiple tasks is a major asset.

4.5.6 Benefits of Implementing Formal QMS

In literature there are a number of benefits associated with formal QMS implementation. Vlachos, Michail and Sotiropoulou (2002) list competitiveness, reliability improvement, increased quality awareness, more efficiency and teamwork as the major advantages of implementation of the ISO/IEC 17025 standard.

Table 4.4.9 Benefits of QMS as Expressed by Questionnaire Respondents

	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Total
C11.1 Customer complaints	0	0	4	11	5	20
	0.0%	0.0%	20.0%	55.0%	25.0%	100.0%
C11.2 Requests for rework	0	0	5	7	7	19
	0.0%	0.0%	26.3%	36.8%	36.8%	100.0%
C11.3 Work contracts/new clients	0	1	7	4	6	18
	0.0%	5.6%	38.9%	22.2%	33.3%	100.0%
C11.4 Process efficiency	0	0	3	10	6	19
	0.0%	0.0%	15.8%	52.6%	31.6%	100.0%
C11.5 Product quality	0	0	0	12	7	19
	0.0%	0.0%	0.0%	63.2%	36.8%	100.0%

Displayed in table 4.4.9 above is what was expressed by questionnaire respondents as benefits of implementing ISO Standards in their organisations. The benefits of implementing ISO standards stated by interviewees, questionnaire respondents and what is generally found in literature was more or less the same. Of course, the importance of each of those benefits differed from one organisation to another. One organisation might have product improvement at their major benefit and another organisation might have reduced customer complaints as theirs. The thin section laboratory's main focus was on improving product quality and the potential of securing new clients. The possibility of achieving other benefits would be added incentive. About 33% of the respondents stated that their organisations experienced an improvement in new work contracts and 38 % stated that the product quality was much better. The integration of interview and questionnaire data paints a clearer picture of what implementing ISO Standards is all about. The challenges that need to be overcome, the infrastructure that need to be put in place and what can be expected after successful implementation. The laboratory experiments revealed that there are ways of improving process and the quality of the products produced. Most laboratories benefit from implementing formal QMS. For university research laboratories, Grocahu et al. (2012) listed: (1) increased customer satisfaction; (2) increased reliability of results and staff's qualifications; (3) decreased malfunction problems of equipment; (4) increased number of tests requests; and (5) receipt of government funds as the observed benefits of implementing structured QMS. The last two benefits stated above are what the thin section laboratory is hoping to consequently achieve after the implementation of ISO/IEC 17025.

On the question of whether formal QMS implementation benefits outweighed its disadvantages, 25% of the questionnaire respondents chose the neutral option, meaning that they neither agreed nor disagreed with that statement. The remaining 75% was split between respondents who strongly agreed (35%) and those who agreed (40%). This was in line with interview respondents who all agreed that the benefits of a formal quality system implementation outweigh the disadvantages they encountered. Perhaps the explanation for the minor disparity in the responses can be explained by what respondent 10 in the interview.

Respondent 10 posited that:

"It is up to the organisation to look at the trade-offs between conforming to ISO standards and not conforming, the cost of inferior quality products is a lot more than the cost of implementing a system that will eliminate the problems that are created by not having one. For our laboratory, the implementation of ISO 17025 had benefits that far outweighed any challenges we faced leading up to the implementation"

4.6 Conclusion

The different data collection techniques had different objectives. The findings from the internal survey informed the laboratory of the prevalent quality defects on the thin sections which led to experiments that would try and eliminate those defects. The interviews and questionnaires sought to get the experiences of ISO 17025 implementation champions and system users. The conducted experiments proved that some defects in the thin sections can be eliminated. Interviews and questionnaire data informed the laboratory of various important things. Though it expressed the amount of difficulties and challenges in implementing ISO/IEC 17025, the findings also informed of how those challenges and difficulties can be overcome and the different options available to organisations that intend to implement ISO/IEC 17025. The next chapter will look at how these findings impact on the thin section laboratory and what can the lab learn from the lived experiences of the study participants and the literature reviewed.

CHAPTER 5: CONCLUSIONS

5.1 Introduction

The previous chapter dealt with the results obtained from the various sources of data used in this study. The data were analysed and discussed in relation to the thin section laboratory. What this chapter seeks to do is to use the discussions from the previous chapters to draw conclusions and make inferences about how those could impact the case being studied. That will be achieved by first looking at what the objectives of the study were:

- To conduct a Gap analysis of quality management in the thin section laboratory in relation to the requirements of ISO 17025
- To assess whether there is scope for formal quality management system implementation in this type of laboratory
- To evaluate whether ISO 17025 would be the right standard for the thin section laboratory.
- To review quality control measures on thin section production and standardise them.

The study had to fulfil these objectives and answer the research questions that went with them. This was done using guidelines from literature and experimental and research data.

5.2 Gap Analysis

Grochau et al. (2012) listed aspects that needed to be checked in order to conduct an effective gap study for implementing ISO 17025 at a university laboratory. Those important aspects include (1) proper functioning and calibration status of equipment; (2) the staff's knowledge and skill; (3) the use of clearly described and validated analytical methods; and (4) the adequacy of the facilities. These aspects were used as a guide in examining the gaps between ISO 17025 requirements and the thin section laboratory's practices. The various gaps that were uncovered are discussed below

5.2.1 Technical Requirements

5.2.1.1 Equipment and materials

In teaching and research institutions, equipment used for tests covered by a formal quality system should not be allowed to be manipulated by students; those used for teaching purposes should stay in other laboratories. The availability of complete instructions regarding the use and maintenance of equipment, as required by the ISO/IEC 17025:2005 standard, and the implementation of intense training and supervision will minimize the effects of the presence of temporary staff (Grochau, 2012).

Prior to the study being conducted, the thin section laboratory had commissioned the use of two new instruments for the preparation of thin sections. The instruments are in good condition, housed separately from student laboratories and are fitted with the latest technological improvements but in terms of ISO 17025 requirements; they are non-compliant as there are no records of the dates of calibration and service to equipment. There are also no operating manuals/work instructions for the various laboratory machines. Periodical servicing of instruments should be done by the suppliers and daily maintenance checks should be done by laboratory personnel and records of those should be kept.

The laboratory uses various suppliers for laboratory consumables. This was recommended by the university governance department to try and root out corrupt practices. The adverse effect of that is that it leads to the inability to track any bad products received and their contribution to product defects. Besides not complying with documentation and records requirements, the thin section laboratory needs to comply with the purchasing and services requirement as well when it comes to equipment and consumables. ISO/IEC 17025:2005:6 state that the laboratory should have a policy and procedure(s) for the selection and purchasing of services and supplies it uses that affect the quality of the tests and/or calibrations. Procedures should exist for the purchase, reception and storage of reagents and laboratory consumable materials relevant for the tests and calibrations. The laboratory should also ensure that purchased supplies and reagents and consumable materials that affect the quality of tests and/or calibrations are not used until they have been inspected or otherwise verified. The laboratory therefore needs to review suppliers, identify one supplier,

perform tests on every new batch of consumables used in thin section prep (mainly the epoxy mix). Records of the tests must be kept and updated with every new batch used.

5.2.1.2 Use of Validated Methods

By documenting procedures, laboratories are more isolated from losing knowledge when lab personnel leave the laboratory for various reasons. There is also consistency in how laboratory measurements are carried out. The laboratory can confidently assign tests to trained personnel knowing that they were trained by skilled people. Thinking about quality and performing measurements in a systematic and identical way every time will permeate the lab. Students that work in the laboratory learn quickly that quality is not a meaningless adjective but something that can be quantified and practiced (Hullihen et al. 2009). One of the major gaps identified during the study was that the laboratory did not have standard operating procedures, work instructions and operating manuals for the methods and machinery used in the laboratory. The reason furnished for that was that the preparation methods differ from one rock type to another and it was a difficult challenge to standardise the method. As one of the laboratory experiments conducted proved, it was possible to standardise the preparation method.

As stated before, research laboratories perform many non-standard tests. This is also true for the thin section laboratory. Many tests are not standardised and are always adapted to suit the clients' requests. The ISO 17025 standard makes provisions for the performance of non-standard methods. ISO/IEC 17025:2005:21 posit that when it is necessary to use methods not covered by standard methods, these should be subject to agreement with the customer and should include a clear specification of the customer's requirements and the purpose of the test and/or calibration. The laboratory also employs many student technicians and has a high staff turn-over, having non documented procedures leaves it at a high risk of losing valuable knowledge when people move on. Standard operating procedures should be drafted for all laboratory equipment and methods of preparation. Efforts to validate the standard methods should be made and a document on validation of non-standard methods should be drafted as those are usually an agreement between the client and the laboratory.

5.2.1.3 Adequacy of Facilities

Laboratory facilities must be adequate for testing and other related activities and in accordance with the test methods and equipment manuals. When necessary,

procedures to control the environmental conditions, in addition to those related to the use of and access to different of areas, should be established (Grochau, 2007). This also impacts on the building's health and safety standards as the thin section laboratory is housed in a multi-purpose building with other activities taking place around the laboratory.

The Thin Section laboratory was fortunate to be in one of the older buildings that the university management identified as needing upgrading. This happened in the year 2014 and upgrades to the analytical services infrastructure within the building were also commissioned. A fume cupboard, dust extractors and air conditioners were installed in addition to changing the electrical and ICT cabling. The upgrades were done to comply with health and safety requirements for the building and the thin section and other laboratories housed in the building benefitted from that. Laboratory facilities were found to be adequate to perform various laboratory functions.

5.2.2 Management Requirements

5.2.2.1 Laboratory Management

Higher education institutions are complex organisations in which the functional and hierarchical relationships among the staff members are not always well defined Rauret et al. (2003). This proved to be true for the thin section laboratory as well and one of the major requirements of ISO 17025 is a proper management structure and having roles in quality management clearly defined. The challenge with thin section laboratory is that its organisational structure is not conventional. The laboratory is headed by a member of the departmental executive team who has "more important" issues to deal with such as teaching, academic commitments, and students. This leaves many day-to-day decisions and running of the laboratory to the technician present at that time. The results of that is responsibilities getting shifted from one technician to another and no accountability when complaints are raised. To comply with ISO 17025 requirements, the thin section laboratory will need to restructure their management structure.

5.2.2.2 Staff's Knowledge and Skills

The laboratory uses many student technicians to perform various functions in the laboratory. This is done to save costs of hiring more technicians while giving students much needed vacation work and experience. While this has the aforementioned

benefits, it also has disadvantages. There is very limited time to train the student technicians and evaluate their competence. ISO/IEC 17025:2005:19 states: “The laboratory management shall ensure the competence of all who operate specific equipment, perform tests and/or calibrations, evaluate results, and sign test reports and calibration certificates. When using members of staff that are undergoing training, appropriate supervision shall be provided. Personnel performing specific tasks shall be qualified on the basis of appropriate education, training, experience and/or demonstrated skills, as required.” The laboratory will need to put training programs in place for all lab personnel and only competent staff should operate lab equipment and perform critical functions. Student technicians should only conduct sample preparation and analysis under supervision from trained and competent technicians.

Zapata-Garcia (2007) stated that there are usually very high levels of expertise in university laboratories which often exceed the job requirements and that some laboratory tasks are often carried out by young researchers at early stages in their careers. Young researchers have career development ambitions and personal research to conduct which affects their dedication to the laboratory activities. This also affects the thin section laboratory. As stated before the laboratory experiences a high turn-over of staff and loses expertise due to various reasons. The laboratory does train staff but once they are competent, they leave for higher paying jobs in industry. Part of the reason why laboratory management wants to create an extra income stream is to supplement technical staff salaries. The thin section laboratory will need to train core staff on quality management systems to supplement their technical knowledge on the functions of the laboratory.

5.3 Scope for Implementing ISO 17025 in the Thin Section Laboratory

Having analysed laboratories’ reasons for implementing ISO/IEC 17025 and reconciled those with the challenges facing the thin section laboratory, it can certainly be confirmed that there is scope for implementing ISO/IEC 17025 in this type of laboratory. Literature shows that even with the two main functions of the laboratory, teaching and research, there is a need for a quality management system. The desired commercialisation of some of the laboratory’s services lends credence to the argument for the need of implementing a quality management system.

5.4 Suitability of ISO 17025 for the Thin Section Laboratory

Research laboratories deal with many uncertainties in measurements as most of the work performed is non-standard. Some of the parameters cannot be quantified or measured. ISO 17025 makes provisions for declaration of uncertainties and estimations. De Vre (2005) stated that there are compatibility questions concerning a quality system, usually associated with an excessively normative approach, and the research activities which require some creativity, independence and flexibility. The concern is that that none of the existing standards, in their current form, can independently, satisfactorily cover all the quality assurance needs of a research and development facility, even though they all present many relevant features. For the thin section laboratory, the implementation of ISO 17025 is a strategic move. It is more for the provision of testing services as much as it is a method of improving service provision to research activities in the university. It was going to be difficult to find a QA system that perfectly fits. ISO 17025 is designed for testing laboratories and for the thin section lab to be able to enter commercial space, it has to comply to this standard. In addition, Grochau et al. (2012), outlined steps for ISO 17025 implementation in a university research laboratory, making possible for the system to be adapted for these type of laboratories.

5.5 Parts of the Thin Section-Making Process that can be Improved

Laboratory experiments conducted were a step towards aligning the laboratory technical processes with ISO 17025 requirements. The tests proved that there are ways to further improve the thin section-making process. Implementing a QA system will make it imperative to devise corrective and preventive actions and to continuously seek improvement opportunities. Further tests and experiments need to be conducted to standardise and validate all analytical methods. Implementing ISO 17025 will compel the laboratory to comply with the standard and ensure that a certain level of excellence is achieved and maintained.

5.6 Conclusion

The gap between the current laboratory processes and ISO 17025 identified was to be very wide but can be narrowed by a few actions. Most of the non-conformities were caused by the laboratory management structure and not having responsibilities assigned. For instance; records and documentation, in terms of instrument and consumables purchases are there in the form of invoices and purchase orders but are

not updated. Assigning this task to a person will ensure compliance. Adjustments to the laboratory management structure need to be made to ensure that there is a person who is directly responsible for the functioning of the laboratory. In terms of technical requirements, the gap is not too wide. The laboratory has adequately trained core personnel, equipment that is in good condition and the lab environment is suitable and conducive for its functions. What needs to be done is validation of methods and assuring the quality of tests results. There is no doubting the benefits that ISO 17025 implementation and accreditation bring to organisation but the cost of implementation may be too big for a research laboratory in an academic institution. The implementation will also seek to address the funding challenges the facility faces. Sourcing partners and collaborators in the ISO 17025 implementation project would assist with the capital needed.

CHAPTER 6: RECOMMENDATIONS

6.1 Introduction

The gap analysis conducted revealed some of the laboratory's shortcomings. Though the laboratory has adequate equipment and facilities to perform its functions and for implementation of ISO 17025, there is more that needs to be done to comply with technical and management requirements.

6.2 Management and Technical Requirements

6.2.1 Technical Requirements

The laboratory must maintain the good condition of the facilities and the laboratory equipment they currently possess. Finding alternative funding streams will assist the thin section laboratory in servicing the equipment and, if the need arises, to purchase new equipment. Implementing ISO/IEC 17025 and competing for testing services contracts is one way of creating that additional income stream. The thin section laboratory will need to write SOPs for laboratory instruments and methods and conduct tests to validate those methods. This can be done internally as there is enough technical know-how already available at the laboratory's disposal.

6.2.2 Management Requirements

Changes to the laboratory's organisational structure would have to be made by the department. This may mean creating a position for a laboratory/technical manager to oversee the day-to-day operations of the laboratory. The manager can concentrate on technical and quality initiatives while the financial aspects are left with the departmental executive member. The laboratory manager will also help with writing proposals for new equipment funding and laboratory upgrades. Another option would be to train technicians on ISO standards and make them responsible for the technical aspects of the laboratory and ISO standards interpretation and implementation. This maybe a lengthy process but it has long term benefits for both the technicians and the department.

From literature and the conducted interviews, it was established that ISO/IEC 17025 implementation is a costly exercise. There is no doubt that ISO/IEC 17025 implementation will benefit the laboratory immensely but laboratory management will need to conduct a proper cost-estimation and ROI analysis. Abdel-Fatah (2010) states that it is not advisable to pursue implementation of ISO/IEC 17025 unless there are

significant gains counteracting the cost of establishing the system, gaining accreditation and maintaining the standard.

6.2.3 Defining the Scope of ISO 17025 Implementation

The thin section laboratory has the option of employing a consultant to assist the laboratory with aligning its processes with ISO/IEC 17025 requirements while training laboratory technicians on the relevant ISO/IEC 17025 clauses for the thin section laboratory. The consultant's scope may be extended to encompass the definition of the scope for implementing ISO/IEC 17025 in the thin section laboratory, the ISO Standard that is suitable for the laboratory and assist with the documentation that is required. One of the deterrents with using consultants is that they usually come at a great cost and may not be a viable option for laboratories with budgetary constraints. Being in a university setting brings with it the advantage of having access to other departments that can offer advice at a fraction of a price that is charged by other industries. Collaborative projects with other departments can lead to much reduced costs on consultancy fees. The ISO/IEC 17025 Standard implementation investigation at the thin section laboratory can be used by laboratory personnel and aspiring quality practitioners from the quality department as a project in their respective studies. This will improve staff's knowledge and skills and assist the laboratory with getting more expertise on implementation.

6.2.4 Process Improvement

In an attempt to align its processes with ISO/IEC 17025 requirements, the thin section laboratory will have to improve its thin section-making process. The tests conducted in this study showed that there are changes that can be made to the preparation procedure to improve the quality of the thin sections. As the laboratory validates its methods, more improvement opportunities will be identified. Implementing ISO/IEC 17025 helps identify process improvement opportunities with corrective and preventative actions. The move towards implementation will also provide such opportunities as the review of the current processes is conducted. The laboratory technicians should conduct tests to determine the standard methods and validate them. Senior researchers can also be invited to give input on how to streamline the process to make it more efficient.

6.3 Conclusion

The thin section laboratory is mainly used for research and teaching activities and to ensure that these important functions of the university laboratory are not adversely affected; proper implementation plans will have to be put in place. For instance, the laboratory technicians can be tasked with ISO/IEC 17025 implementation preparations while using student technicians to prepare most of the specimen used for teaching and research activities. This will ensure that the day-to-day activities of the laboratory continue while investigations for quality improvement, cost-saving and fundraising are conducted. This study found that there are many difficulties with implementation of ISO/IEC 17025 standard with the cost implications being one of the major ones. It is costly to implement and conform to ISO/IEC 17025 standard but university laboratories have access to skills that other organisations have to pay big money for. Laboratory management have the option seeking collaborative projects with other departments or industry sponsors to keep the implementation costs at a minimum. ISO/IEC 17025 Implementation will open the laboratory up to many more opportunities which will, in the long run, benefit researchers and students and help sustain the facility.

References

Fellows , R. F. & Liu, A. M., 2015. *Research Methods for Construction.* s.l.:John Wiley and Sons.

Fernandes, E. et al., 2006. Quality System Implementation in a Brazilian University. *Accreditation and Quality Assurance,* 10(11), pp. 594-598.

Flyybjerg, B., 2006. Five Misunderstandings about case-study research. *Qualitative Inquiry,* 12(2), pp. 219-245.

Forza , C., 2002. Survey Research in Operations Management: a Process-based perspective. *International journal of Operations and Production Management,* 22(2), pp. 152-194.

Gall, M. D., Borg, W. R. & Gall, J. P., 1996. *Educational Research: An Introduction.* s.l.:Longman Publishing.

Grochau, I. H., Ferreira, C. A., Ferreira, J. Z. & ten Caten, C. S., 2010. Implementation of a quality management system in university test laboratories: A brief review and new proposals. *Accreditation and Quality Assurance,* 15(12), pp. 681-689.

Grochau, I. H. & ten Caten, S. C., 2012. A process approach to ISO/IEC 17025 in the implementation of a quality management system in testing laboratories. *Accreditation and Quality Assurance,* Issue 17, pp. 519-527.

Halvey, A., 2003. The Benefits of Calibration and Testing Laboratories May Gain from ISO/IEC Accreditation. *Accreditation and Quality Assurance,* 8(6), pp. 286-290.

Hennink , M., Hutter , I. & Bailey, A., 2010. *Qualitative Research Methods.* s.l.:Sage.

Hoshmand, L., 2003. Can lessons of history and logical analysis ensure progress in psychological science?. *Theory and Psychology ,* 13(1), pp. 39-44.

Huber, L., 2009. *Understanding and Implementing ISO/IEC 17025, a primer,* s.l.: agilent.com.

Hullihen, K., Fitzsimons, V. & Fisch, M. R., 2009. Establishing an ISO 17025 compliant laboratory at a university. *International Journal of Modern Engineering,* 10(1), pp. 55-64.

Johnson, R. B. & Onwuegbuzie, A. J., 2004. Mixed Methods Research: A paradigm whose time has come. *Educational Researcher,* 33(7), pp. 14-27.

Karami, A., Rowley, J. & Analoui, F., 2006. Research and Knowldge Building in Management Studies: an Analysis of Methodological Preferences. *International Journal of Management,* 23(1), p. 43.

Kenett, R., 2007. Cause-and-Effect Diagrams. *Wiley StatsRef: Statistics Reference Online.*

Krapp, M., 2001. Quality Assurance in Research and Development: An Insoluble Dilemma?. *Journal of Analytical Chemistry,* 317(6), pp. 704-713.

Mann , R. & Kehoe, D., 1995. Factors Affecting the implementation of TQM. *International Journal of Quality and Realiability Management,* 12(1), pp. 11-23.

Mark, M. M., Feller, I. & Button, S. B., 1997. Integrating qualitative methods in a predominantly quantitative evaluation: A Case Study and some reflections. *New directions for evaluation,* 1997(74), pp. 47-59.

Morse, J., 1991. Approaches to qualitative-quantitative methodological triangulation. *Nursing Research,* 40(2), pp. 120-123.

Nara, Y., 2003. Research Laboratories Conforming to ISO/IEC 17025. *International Journal of PIXE,* 13(1 and 2), pp. 5-9.

Ndafyaakalo, M., 2010. *Implementing ISO/IEC 17025: The Challenges and Triumphs of a Municipal Laboratory.* Drakensberg, South Africa, s.n.

N, K., 1994. *kuleuven.be.* [Online]
Available at: perswww.kuleuven.be
[Accessed November 2015].

Onwuegbuzie, A. J. & Leech, N. L., 2005. On becoming a pragmatic researcher: The importance of combining quantitative and qualitative research methodologies. *International Journal of social research methodology,* 8(5), pp. 375-387.

Park, J., Nam, G. & Choi, J., 2011. Parameters in cause and effect diagram for uncertainty evaluation. *Accreditation and quality assurance,* 16(6), pp. 325-326.

Pinsonneault, A. & Kraemer, K., 1993. Survey Research Methodology in Management Information Systems: An Assessment. *Journal of management Information Systems,* 10(2), pp. 75-105.

Pope, C., Ziebland, S. & Mays, N., 2000. Analysing Qualitative Data. *BMJ,* 320(7227), pp. 114-116.

Rauret, G. & Compano, R., 2003. Quality Management in undergraduate laboratories: A systematic approach to its implementation. *Accreditation and Quality Assurance,* 142(3), pp. 177-185.

Remenyi, D. & Williams, B., 1998. *Doing Research in Business and Management: An Introduction to process and Method.* s.l.:Sage.

Richards, T. & Richards, L., 1994. Using Computers in Qualitative Analysis. In: N. Denzin & Y. Lincoln , eds. *Handbook of Qualitative Research.* s.l.:Sage.

Ritchie, J. & Spencer, L., 2002. Qualitative Data analysis for Applied Policy Research. *The Qualitative Researcher's companion,* Volume 573, pp. 305-329.

Rodima, A. et al., 2005. ISO 17025 Quality System in a University Environment. *Accreditation and Quality Assurance,* 10(7), pp. 369-372.

Rubin, A. & Babbie , S., 2001. *Research Methods for Social Work.* 4th ed. USA: Wadsworth/Thomson Leaming.

Sandelowski, M., 2000. Focus on Research Methods: Whatever Happened to Qualitative Description?. *Research in Nursing and Health,* 23(4), pp. 334-340.

Shaw, E., 1999. A Guide to the Qualitative Research Process: Evidence from a Small Firm Study. *An International Journal of Qualitative Market Research,* 2(2), pp. 59-70.

Suri, H., 2011. Purposeful Sampling in Qualitative Research Synthesis. *Qualitative ResearchJournal,* 11(2), pp. 63-75.

Teddlie, C. & Yu, F., 2007. Mixed methods sampling a typology with examples. *Journal of mixed methods research,* 1(1), pp. 77-100.

Then, D., 1996. A study of organisational response to the management of operational property assets and facilities support services as a business resource.

Trost, J., 1986. Statistically non-representative stratified sampling: A sampling technique for qualitative studies. *Qualitative Sociology ,* 9(1), pp. 54-57.

Vajda, N., Balla, M., Molnar, Z. & Bodizs, D., 2006. On the way to formal accreditation. *Accreditation and Quality Assurance,* 10(11), pp. 559-602.

Valcarcel, M. & Rios, A., 2003. Quality Assurance in Analytical BodiesEngaged in Research and Development. *Accreditation and Quality Assurance,* 8(2), pp. 78-81.

Van Teijlingen, E. R., Rennie, A. M., Hudley, V. & Graham, W., 2001. The importance of conducting and reporting pilot studies: examples of Scottish births survey. *Journal of advanced nursing,* 34(3), pp. 289-298.

Vermaercke, P., 2000. Sense and Nonsense of Quality Assurance in an R&D Environment. *Accreditation and Quality Assurance,* 5(1), pp. 11-15.

Vlachos, N. A., Michail, C. & Sotiropoulou, D., 2002. Is ISO/IEC 17025 a Benefit or Hindrance to Testing Laboratories? The Greek Experience. *Journal of Food Composition and Analysis,* 15(6), pp. 749-757.

Yin, R., 1994. *Case Study Research: Design and Methods.* s.l.:Sage.

Zapata-Garcia, D., Llaurado, M. & Rauret, G., 2007. Experience of implementing ISO 17025 for the accreditation of a university testing laboratory. *Accreditation and Quality Assurance,* Volume 12, pp. 317-322.

Appendices

Appendix 1: Request to complete questionnaire

University of Johannesburg
29 September 2014

Dear participant

I am a student studying towards a Master's degree in Operations Management at the University of Johannesburg. I am undertaking a research project to investigate Quality Control in a University Laboratory: A Study of ISO-17025 Implementation in the Thin Section Laboratory. To this end I kindly request that you complete the following short questionnaire regarding your experiences with quality management systems (prior, during and post implementation). It should take no longer than 10 minutes of your time. Your response is of the utmost importance to me.

Please note that full ethical considerations such as confidentiality, anonymity, your full consent and a formal approval from your organisation to conduct this study will be obtained to ensure that all concerns on you as a research respondent are adequately addressed.
Kindly return the completed questionnaire to the email provided. Arrangements to collect the hand-filled questionnaires will be made and communicated.

Results of the survey and any feedback will be made available on request.

Should you have any queries or comments regarding this survey, you are welcome to contact me telephonically on 011 717 7441 or by e-mail at musa.ceb@gmail.com

Yours sincerely
Musa Cebekhulu
Operations Management Masters Candidate
University of Johannesburg

PLEASE ANSWER THE FOLLOWING QUESTIONS BY CROSSING (×) THE RELEVANT BLOCK OR WRITING DOWN YOUR ANSWER IN THE SPACE PROVIDED.

Section A – Background information

1. What is your highest educational qualification?

Grade 12 (Matric, std. 10)	
Post-Matric Diploma or certificate	
Baccalaureate Degree(s)	
Post- Graduate Degree(s)	

2. Which of the following best describes the laboratory you work in?

Production	
Manufacturing	
Calibration	
Testing	
Research and Development	

3. Which of the following best describes the quality management system used in your laboratory at the present time?

Do not use a quality management system	
Good Laboratory Practice	
ISO 9001	
ISO 17025	
Other (please specify)	

Section B

This section deals with the reasons for implementing ISO 17025, the respondent's involvement and how the implementation took place.

4. Have you been involved in any quality management system implementation?

Yes	
No	

5. Based on your experience, please rate the influence of the following role player on the successful implementation of ISO 17025 in an organisation.

	Not influential	Slightly influential	Somewhat Influential	Very influential	Extremely influential
Project Owner					
QA Manager					
Senior management					
QA Team					

6. Below is a list of reasons for implementing ISO 17025 in a laboratory or organisation. Please rate how important each reason was for implementing ISO 17025 at your organisation/laboratory.

Possible reasons for implementing ISO 17025	*Not important*	*Slightly Important*	*Neutral*	*Moderately important*	*Very Important*
Improving the quality of the products and services					
To get accreditation and audited					
To streamline processes and simplify work procedures					
To reduce customer complains					
To continually improve data quality and lab effectiveness					

7. When implementing ISO 17025, what level of priority was given to each of the following management requirements?

Management requirements	Not a priority	Low priority	Medium Priority	High priority	Essential
Document control					
Review of tenders and contracts					
Handling Customer complains					
Control of nonconforming test work					
Continuous improvement					

8. Based on your experience with ISO-17025 implementation, please rate the importance of each of the following technical requirements.

Technical requirements	Not at all important	Slightly Important	Neutral	Moderately Important	Very Important
Personnel					
Equipment					
Methods Validation					
Assuring the quality of test results					
Sampling					

9. Below is a list of possible disadvantages of implementing ISO 17025. In your experience, did you, at any point during the implementation process encounter any of them?

Possible disadvantages	Never	Rarely	Occasionally	Often	Always
Cumbersome documentation					
Budgetary constraints					
Lack of resources					
Time constraints					
Lack of staff interest/participation					

Section C

This section deals with benefits and/or disadvantages of ISO 17025 implementation

10. The organisation benefited from ISO 17025 implementation.

Strongly disagree	disagree	neutral	agree	Strongly agree

11. Since the implementation of ISO 17025, how has each of the following attributes been affected?

	Much worse	Somewhat worse	About the same	Somewhat better	Much better
Customer complaints					
Requests for rework					
Work contracts/new clients					
Process efficiency					
Product quality					

12. The advantages of implementing ISO 17025 outweigh any disadvantages.

Strongly disagree	Disagree	neutral	Agree	Strongly agree

13. Would you recommend ISO 17025 implementation to other laboratories?

Extremely unlikely	unlikely	neutral	likely	Extremely likely

Thank you for your co-operation in completing this questionnaire. Kindly return the questionnaire as specified in the cover letter.

Appendix 2: Interview questions

1. What were the main reasons for ISO/IEC 17025 implementation?
2. What do you regard as the main or most important step towards implementing ISO/IEC 17025?
3. How did you select the correct ISO Standard for your organisation?
4. What was your strategy for ISO 17025 implementation i.e. did the implementation take place company-wide or was it departmental and gradual?
5. What were some of the challenges encountered during implementation?
6. How did you overcome those challenges?
7. Is your organisation accredited for just one or a combination of systems?
8. What was the reason for combining different quality management systems or for deciding that one is enough?
9. What is the most effective way to achieve ISO accreditation?
10. How has ISO/IEC 17025 implementation benefited your organisation?
11. What are the disadvantages of ISO/IEC 17025 implementation?
12. Would you recommend ISO/IEC 17025 implementation to other laboratories?