University of Southern Queensland

Faculty of Engineering and Surveying

Improvements to the Calibration of Electronic Distance Measurement Equipment (EDME)

A Dissertation Submitted by

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In Fulfilment of the requirement of

Course ENG4111 and ENG 4112 Research Project

Towards the degree of

Bachelor of Spatial Science (Surveying)

Submitted: 28th October, 2015

ABSTRACT

As Electronic Distance Measurement Equipment (EDME) technology significantly advances, so too must the way instruments are calibrated. Valuable time and resources are committed to ensuring EDME is calibrated to ensure national standards are met. As such, it is vital that the methods employed for calibration are the most appropriate for the instruments used.

In order to assist the profession in this regard, this paper investigates the current EDME calibration baseline designs used in Queensland and analyses the suitability of each in order to devise an alternative baseline design. The methodology used was to identify key characteristics of an existing baseline design and select the most accurate of those to construct a new design. This process was then applied over multiple designs and the results analysed and compared to determine the viability of the alternative design.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Rhys Daniel Wayne Pescod

U1006119

Acknowledgements:

This research project was carried out under the guidance and supervision of Mr Gregory Williams, Cadastral Surveyor of Moreton Bay Regional Council.

I would like to thank Dr Glenn Campbell who has supervised the completion of this research project. This project would not have been achieved without his guidance and support.

I wish to specifically thank Colin Moorhead who provided the required software for this project and assisted my understanding of its application. Further thanks to Isaac Stiller of DNRM who has provided valuable advice throughout this research project.

Finally, I would also like to thank my wife Shannon for her ongoing and unwavering support and understanding throughout this research project, without whom I would not have been able to achieve a completed project.

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CHAPTER 1 - Introduction

1.1 Project Topic Description

The reliability and accuracy of Electronic Distance Measurement Equipment (EDME), like any equipment, is critical. To ascertain this, EDME is calibrated on government maintained baselines. The calibration process identifies any existing errors of the instrument so that adjustments may be made to account for those errors. The design of a calibration baseline is largely determined by the need to eliminate specific types of error.

This project dissertation will investigate the different EDME calibration designs and particularly focus on the current design format used in Queensland and the errors they address. It is theorised that an alternate calibration baseline design is possible as technological advances in EDME means that some types of errors (particularly 'cyclic error') may no longer be as prominent in modern day instruments, and therefore there may be scope to redesign the current baseline used in Queensland. The possibility of an alternative legally traceable calibration baseline will therefore be explored.

1.2 Project aim and Objectives

The aim of this project is to investigate the current baseline designs used for the calibration of EDME, undertake an analysis of these current designs and research alternative methods that have been previously proposed and offer a fresh alternative EDME baseline design.

The objective of an alternative EDME calibration baseline design is to ensure that the types of errors that current calibration baselines address are still relevant and required to be corrected when using modern day instruments. The alternative design will focus on the fact that cyclic error may not need to be considered in the design due to advances in technology. In this respect, a more efficient calibration baseline, both economically and physically, is possible.

1.3 Project Background

The Department of Natural Resource and Mines (DNRM) is the authority appointed for the verification of (and re-verification) of “length”. In order to perform their obligations as a verifying authority, DNRM provide and maintain EDME Baselines throughout the state of Queensland for the purpose of calibrating surveying equipment.

There are currently 16 certified EDME Baselines in Queensland. Table 1.1 identifies the length and locations of each baseline.

Location	***Length***	***Location***	***Length***
Aloomba: Along railway line.	730m	**Maroochy:** Within airport grounds	1004m
Bundaberg: Within airport grounds.	1021m	**Maryborough**	1021m
Caboolture: Along railway line.	1148m	**Mica Creek**	1021m
Cooktown: Within airport grounds.	1021m	**Toowoomba**	1011
Gold Coast: Within sewage treatment plant.	1051m	**Townsville**	(1)969m (2)975m
Goonyella	1029m	**Tungamull**	870m
Leyburn: Within scientific reserve	1082m	**Walkamin:** Within scientific reserve.	1083m
Mackay	880m		

Table 1.1: Qld EDME Calibration Baselines (DNRM)

Perusal of the Regulation 13 Certificates of each baseline reveals that all Queensland calibration baselines consist of seven pillars and span, on average, approximately one kilometre of unobscured land. As demonstrated in Table 1, baselines are often situated in an area with restricted access, such as within airports or along railway lines. These places provide an open, unobscured area large enough to accommodate the seven pillar method.

In addition to modern instruments potentially outgrowing current calibration methods, there are two further issues with the current baselines:

1. There are a limited number of certified baselines, affecting availability and accessibility for surveyors.
2. There are difficulties in finding suitable land given the distance required for seven pillar baselines especially in high populated areas.

1.4 Conclusion

The need to undertake this dissertation derives from the lack of suitable EDME baselines in highly populated areas such as Brisbane. In addition to the lack of EDME baselines, there is a need to investigate whether the current 7 pillar design is now required to calibrate modern day instruments. This hasn't yet been investigated to ascertain if the current baselines are changing and adapting with advances in technology, particularly with the reference to Cyclic error.

This project will aim to provide an alternative calibration baseline design. The alternative baseline design aims to be more efficient in the calibration process whilst ensuring legal traceability of the EDME. Further, the alternative baseline seeks to achieve greater economy in maintenance and installation of new baselines as well as being more versatile to allow the new baselines to be installed in more suitable locations.

CHAPTER 2 - Literature Review

2.1 Introduction

This chapter will provide the intellectual and historical basis for the alternative baseline design by conducting a review of the literature relevant to the calibration of EDME.

There is a substantial amount of literature in regards to baseline designs. However, very little material specifically investigates the advancements in technology in modern EDME and the way in which this affects the calibration process. Research has indicated that the relationship between the two is yet to be explored.

The aim of this chapter is to utilise and review the available literature. The primary resources for this project were formally published, peer reviewed sources, supplemented by anecdotal evidence of industry professionals.

2.2 History of EDME

A number of different surveying instruments have been used over time to measure distance. By the 1980's distances were predominantly measured electronically.

Early EDME, such as a Geodimeter, utilised light waves and were only able to measure long distances at night (Rueger, 1980). Next came instruments that used radio waves, such as the Tellurometer. The 1960's saw a shift to Infrared light sources in instruments. Modern instruments are total stations, utilising a coaxial, visible red laser and are based on the principle of phase measurement.

2.3 Principles of EDME

The electronic measuring of a distance involves the emission of a signal from the instrument to a reflector which returns the signal to the instrument. The electronic signal has a sinusoidal wave form. The outgoing and incoming wavelengths are compared and, rather than measuring the travel time of the signal, the signal structure is measured to determine the phase lag (Rueger, 1980).

As it is emitted by the EDME at a specified frequency, the wavelength (λ) is a known quantity. The signal leaves the EDME at 0o phase and completes a certain amount (n) of full phases on its way to and from the reflector. The signal then returns to the EDME at an angle that is between 0o and 360o creating a partial wavelength (p). Therefore, the total distance is (n λ + p), as demonstrated in Figure 1.1.

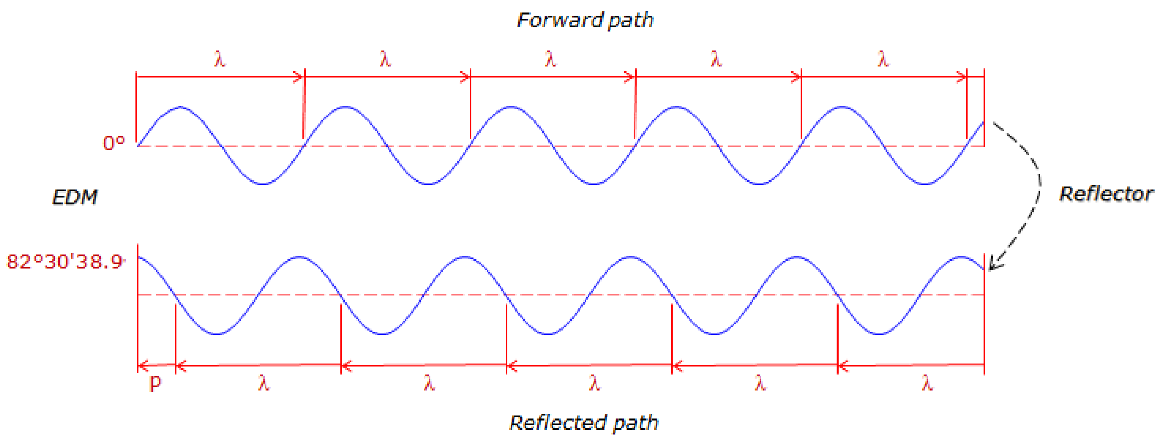


Figure 1.1: EDME sinusoidal wavelengths: (*n* λ + p)

Modern EDME instruments are based on this principle regardless of light waves, infrared waves or microwaves as carrier waves**.**

2.3 Legal traceability

Legal traceability is the linking of the distance measurement to the definition contained in the relevant legislation. If a distance, or length, is proven traceable to the national standard, the validity of the measurement will be strengthened should it be scrutinised by a court of law.

Firstly, Regulation 73 of the National Measurement Regulations 1999 (Cth) provides that an authority is to be appointed for the verification and re-verification of length and the certification of measuring instruments. DNRM is the verifying authority of Queensland and is therefore charged with providing legal traceability of length for surveying EDME. To achieve this, DNRM maintain the EDME baselines throughout Queensland.

Further, surveyors have a legal obligation to ensure that their equipment is standardised. Section 20 Survey and Mapping Infrastructure Regulation 201 (Qld) provides that a cadastral surveyor who carries out, or is responsible for carrying out, a cadastral survey must ensure any survey equipment used for the survey is:

a) Standardised; and
b) Capable of achieving the accuracy stated in the relevant survey standard for cadastral surveys.

This statutory provision of instrument verification/standardisation establishes traceability of the instruments measurements to the national standard.

Equipment is standardised (and therefore legally traceable) if:

1. The measurements are made by an appropriate EDME instrument that has been tested according to the recommended procedure on an EDME Baseline;

2. At the time of testing, the EDME baseline held a valid and current Regulation 13 Certificate issued by DNRM (under the *National Measurement Act 1960* (Cth);
3. That baseline was calibrated according to approved procedures and using the designated EDME baseline calibration instrument;
4. The calibration instrument and supporting instruments hold a valid and current calibration certificate.

The Intergovernmental Committee on Surveying and Mapping – Special Publication 1 (SP1) provides that EDME be calibrated once per year. Additionally, they should be calibrated after each repair or maintenance. DNRM are soon to release the updated Cadastral Survey Requirements (Version 7) which will mirror the provisions of SP1.

To ensure legal traceability occurs as provided above, the *Legal Traceability of Length for EDME (LTOLE)* (DNRM, 2012) defines DNRM's recommended procedure for carrying out EDME comparison.

2.4 Calibration of EDME

EDM instruments inherently contain errors. To determine the error of an instrument it must be calibrated over a known distance. Calibration is the process of comparing a measured value to a known value, e.g. by comparison to a standard of the physical quantity length (Janssen and Watson, 2014). The calibration process will identify the nature and extent of the errors of an instrument.

The three primary sources of error that are determined by calibration are: zero constant error, scale error and cyclic error (Rueger 1980). Emenike (1982) also identified constant, scale and cyclic errors as the most 'serious' of error groups in EDME instruments and states that they should be eliminated. The two that remain accepted as sources of error are the zero constant error and scale error. As technology has advanced it has been suggested that cyclic error is now an insignificant consideration (Ellis, 2013). However, cyclic error remains relevant to any discussion regarding EDME calibration as it remains vital to legal traceability.

2.4.1 Constant Error

Also known as the zero or index error, the constant error is an algebraic constant to be applied directly to every measurement. It is caused by three factors:

1. Electrical delays, geometric detours and eccentricities in the EDM instrument.
2. Differences between the electronic and mechanical centres of the EDM instrument.
3. Differences between the optical and mechanical centres of the reflector.

The zero error arises from the distance measuring points of the EDM instrument and of the reflector not being coincident with the vertical axes at either end of the measured line. This error may vary with a change of reflector, after receiving impacts, with different instrument mountings and after service (Janssen, 2015).

2.4.2 Scale Error

The scale error is linearly proportional to the length of the measured line. It is caused by:

1. Variations in the modulation frequency of the EDM instrument. This may be due to ageing or drift of the frequency oscillator used or to temperature effects on the oscillator;

2. Errors in the measured temperature, atmospheric pressure and humidity, which affect the velocity of the signal propagation;
3. Non-homogeneous emission/reception patterns from the emitting and receiving diodes (phase inhomogeneities).
4. Errors in the collection and use of atmospheric data. This includes the use of uncalibrated thermometers/barometers, not taking atmospheric measurements in the shade and the incorrect entry of the atmospheric correction into the EDM (Ellis, 2013).

The scale factor will generally vary for subsequent calibrations within the accuracy specification of the instrument because it is dependent on the instrument's modulation frequency, which may change with variations in the ambient temperature. To a lesser extent, the scale factor can also change as a result of frequency drift and ageing of the frequency oscillator. Consequently, if the scale factor falls within the instrument's specification, it should not be applied as a correction to measured field distances.

If the scale factor falls outside the instrument's specification, the instrument should be returned to the manufacturer for service. However, it is advisable to repeat the calibration under different climatic conditions both to confirm the result and to observe if the scale factor changes with different ambient temperatures. The thermometers and barometers used in the calibration should also be re-calibrated against a certified standard as an error in temperature and pressure readings will contribute to the scale error of measured distance (Janssen 2015).

2.4.3 Cyclic Error

The precision of an EDM instrument depends largely on the precision of the internal phase measurement. Phase measurement error can occur due to unwanted feed (electrical and optical interference) through the transmitted signal onto the received signal (Khalil 2005). Bannister et al. (1998) describes the cyclic error as a function of the actual phase difference measured by the EDM instrument.

It varies across the modulated wavelength and is generally sinusoidal with a wavelength equal to the unit length of the EDM device (Couchman 1974). The unit length is the scale on which the EDM instrument measures the distance and is derived from the fine measuring frequency. The unit length is equal to exactly one half of the EDM instruments modulation wavelength (Rüeger, 1996).

As the cyclic error repeats itself for every unit length contained within a measured distance, its sign and magnitude vary depending on the length measured. Cyclic error is known to increase in magnitude as the instrument's components age (Janssen, 2015).

Ollis (2007) identified that early EDME instruments generally contained a cyclic error of approximately 5 – 10 mm, while modern EDME instruments have a much smaller cyclic error in the range of 1 – 2 mm. This small cyclic error has been labelled 'negligible' (Janssen 2015) and has been said to have an insignificant effect (DNRM, 2012). Consequently, LTOLE states cyclic error is not required to be determined in calibration (DNRM, 2012).

2.5 Methods of Calibration

EDME is calibrated by measuring a combination of distances on a baseline. A key feature of an EDME baseline is to enable the determination of all instrument errors to an appropriate level of precision (DTPLI, 2014). Ruger (1989 "Baseline Design Parameters") identifies three key calibration Baseline Designs. These are the 'Heerbrugg', 'AARAU' and 'Sprent/Zwart' designs.

The difference between these designs lies in the associated methodology used to determine cyclic error, and the observation procedures applicable to each one. Put simply, short distance calibrations aid in determining the zero constant error. Long distances assist in determining scale error. A design objective is to ensure that these are determined without any cyclic error contributions.

2.5.1 HEERBRUGG/SCHWENDENER.

The Schwendener baseline design features an almost equal distribution of the distances measured in all combinations over the baseline length as well as over the unit length of the distance metre. This design is said to permit the detection of all distance-dependent errors, including cyclic errors (Schwendener, 1972; Rüeger, 1996.) The original design consisted of seven stations, providing 21 observations in all combinations and it happened to be a total length of 1021.5 metres. It is based on a unit length of ten metres.

The Schwendener design is based on four input parameters:

U = unit length of distance metre(s) to be tested

A = shortest distance on baseline (multiple of U)

C_o = desired total length of baseline

n = number of baseline stations.

A larger number of baseline stations (or pillars) will result in an increased number of observations (over various combinations of distances), translating into a higher precision of the resulting zero constant.

2.5.2 AARAU DESIGN

As explained by Rueger (1989) the AARAU baseline design features baseline sections which are exact multiples of the unit length. Assuming that the amplitudes and phases of the cyclic errors do not change over the length of the baseline the cyclic errors will affect each combination measured on the baseline by an equal amount. Any cyclic errors will therefore map into the zero constant error which is derived from the baseline measurements (Rueger, 1989). Cyclic errors must be determined separately on special cyclic error test lines and the bias of the zero constant error removed.

2.5.3 HOBART/SPRENT ZWART

Proposed by Sprent & Zwart (1978), the Hobart design has stations spaced at equal intervals over the entire baseline range. It is not based on the measurement of all combinations of distances like the Heerbrugg and AARAU designs. It requires that all true baseline distances be known at all times.

The additive constant and scale error are able to be determined independent of cyclic error on Sprent/Zwart baselines because their design has the effect of cancelling out cyclic error (DTPLI, 2104). If pairs of measurements are taken from pillars separated by half the unit length of the EDM, the cyclic error affecting each pair will be equal in magnitude and opposite in sign. An analysis, which treats the measurements as pairs, can eliminate the effect of cyclic error.

2.5.4 BASELINE DESIGN IN AUSTRALIA

Queensland EDME calibration baselines conform to current best practice in that they are all Schwendener design (1972) and consist of seven pillars (as noted on the Regulation 13 Certificate of each baseline).

New South Wales EDME baselines also follow the Schwendener/Heerbrugg model, however have significantly fewer pillars. Many New South Wales baselines consist of only 4 pillars (Janssen 2015; Ellis 2013). It was recommended (Rueger 1992) that 4 pillar baselines be upgraded to 5 or 6 pillars. This will increase redundancies which will allow for more accurate EDME calibration. As such, New South Wales is seeking to align their EDME baselines with best practice principles and upgrade the EDM infrastructure (Ellis 2013).

Victorian EDME baselines consist of Sprent/Zwart (Hobart) baseline design, Schwendener design and custom designs intended to accommodate the mass of EDM unit lengths in use. The original Sprent/Zwart design has been altered in Victoria by slightly changing the pillar locations. DTPLI (2014) claims this allows the additive constant to be determined with greater precision. Nevertheless, calibrations using this design are marginally less precise than other baseline designs, as fewer combinations of distances are measured. The great advantage of the Sprent/Zwart method is its ease of use, and this unquestionably offsets the slightly lower precision.

It therefore appears commonly accepted that the higher the number of distances observed, the more reliable the determination of instrument correction will be.

2.6 Alternative Calibration Methods

Alternative methods of calibrating EDME instruments have previously been investigated. Rather than to simply improve on traditional baseline calibration methods, the research outlined below sought to introduce a completely new method of calibration.

2.6.1 GNSS Calibration

Global Navigation Satellite Systems (GNSS) Surveying involves the collection of precise code and carrier phase measurements recorded simultaneously at two or more survey control marks using GNSS equipment. Those measurements can then be processed to derive GNSS baselines (SP1, 2014).

Complex mathematical algorithms are used within the GNSS manufacturer's software packages to determine linear distances between respective positions. These algorithms are not available for analysis, as they are patented products. Therefore, it is not possible to determine how distances measured by GNSS are calculated (Bissett, 2008).

As concluded by Bissett (2008), GNSS measurements do not provide the accuracy over shorter distances that EDM instruments do. For example, the manufacturer's specifications of a Trimble r7 note that horizontal error is +/- 10mm + 1ppm RMS.

As this falls short of the accuracy required for EDM calibration, GNSS is not a suitable method.

2.6.2 Compact Laboratory Calibration

Khalil (2005) investigated an alternative method of calibration using compact laboratory calibration baselines. This involved using mirrors to create a zigzag line to enable the determination of the zero constant of an EDM instrument. It was identified that shorter distances assist in the determination of the zero constant while longer distances help solve the scale component. Importantly, in Khalil's research, the scale component of an EDM instrument was not determined using this compact baseline method and only the zero constant was addressed in this research. Therefore, while it is an alternative approach, the research did not prove that it is a suitable one.

CHAPTER 3: Methodology

3.1 Introduction to Project Methodology

Prior to conducting any field observations or reductions the alternative proposed baselines have to be designed and established. The design of the alternative baselines is an imperative part of this dissertation as they will be compared and analysed against the standard 7 pillar method currently used.

The key characteristics that the alternative baseline designs seek to achieve are:

- Fewer pillars to improve efficiency for Surveyors;
- Shorter overall distance to make it easier to install in more locations;
- High accuracy to ensure legal traceability; and
- Economically cheaper to install and maintain.

Once the alternative baselines have been designed, observations will be carried out over the Caboolture EDM Baseline. These observations will be reduced and comparisons will be made between the current standard seven pillar method and the alternative designs.

Once the observations have been reduced and comparisons made, one of the alternative baselines will be chosen as the new proposed baseline for this dissertation. Alterations may be made to this baseline design to achieve a positive balance between the above key characteristics which the design seeks to achieve.

3.2 Caboolture EDM Baseline

The Caboolture EDM baseline was originally built and designed in 1972 by Colin Moorhead of then Caboolture Shire Council. The Baseline was then rebuilt in 2008 by Greg Williams (Moreton Bay Regional Council). The rebuild saw the baseline shift approximately 19.5m to the East due to the duplication of the North Coast Rail Line.

The Caboolture EDM baseline design is based on the Schwendener model. The Regulation 13 Certificate of Verification confirms the baseline consists of 7 concrete pillars. The distance between each pillar varies from as little as 64.874m (pillar 0-1) and as great as 1148.526m (pillar 0-6). See Figure 3.1 for an aerial photo of the baseline depicting the location of each of the 7 pillars.

Figure 3.1: Aerial Photograph of the Caboolture EDM Baseline

The Caboolture EDM baseline was designed for EDME with a unit length of 10m. Figure 3.2 demonstrates the distance modulo of unit length of the Caboolture EDM baseline. Using the modulo function (which returns the remainder obtained when dividing one number by another, e.g. 42.8 mod 10 = 2.8), it can be tested whether the baseline design delivers an equal distribution of the distances measured in all combinations over the unit length of the EDME (Ellis et al, 2013). It is shown that the 21 baselines are relatively evenly distributed over the 10m unit length ensuring accuracy in determining any cyclic error.

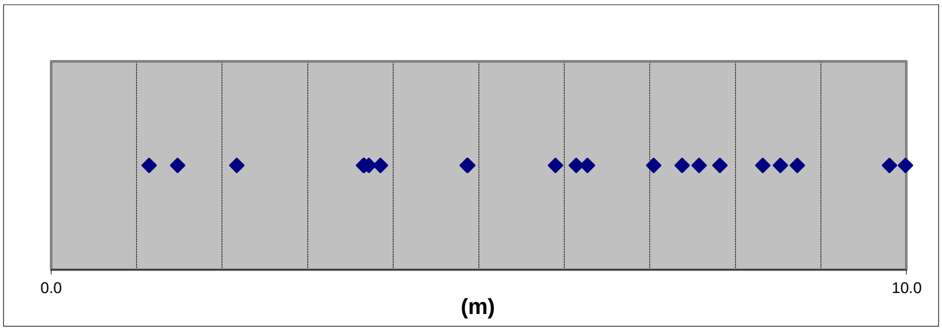
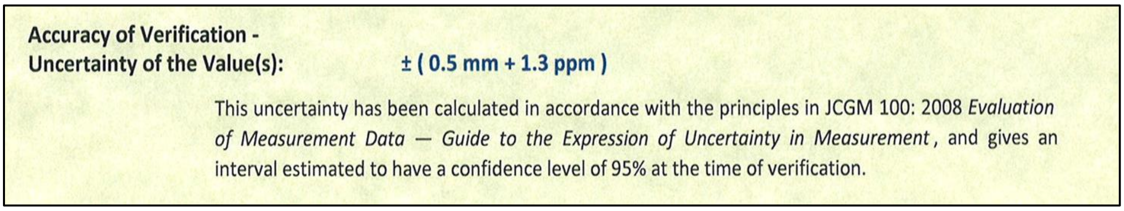


Figure 3.2: Distance modulo of Unit Length of the Caboolture range (10m). Each of the 21 baselines are shown

The Regulation 13 Certificate of the Caboolture EDM baseline identifies that the accuracy of verification of the EDM baseline as having an uncertainty of value(s) of +/- (0.5mm + 1.3ppm). See Figure 3.3.



Accuracy of Verification -
Uncertainty of the Value(s): **± (0.5 mm + 1.3 ppm)**

This uncertainty has been calculated in accordance with the principles in JCGM 100: 2008 *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement*, and gives an interval estimated to have a confidence level of 95% at the time of verification.

Figure 3.3: Uncertainty of Values of Caboolture EDM baseline.

3.3 Alternative Baseline Designs

It was decided that initially three (3) alternative baseline designs will be tested. Three alternatives will allow a thorough comparison of results. Each baseline design will be based on the Caboolture EDM baseline and will use the certified distances between the pillars.

One of the main characteristics for the alternative baseline designs was fewer pillars to improve efficiency for surveyors. Due to this characteristic the three alternative designs will consist of:

Design 1: Four pillar combination.

Design 2: Five pillar combination.

Design 3: Six pillar combination.

In finalising the designs, the accuracy of each pillar combination will be determined by calculating a number of combinations. It is anticipated some pillar combinations will be less accurate than others. Therefore the pillar combinations used in the design will be selected based on the level of accuracy.

To determine the accuracy of each pillar combinations, a least squares adjustment spread sheet prepared by Bruce Harvey from the University of New South Wales will be used. See Appendix B for an example.

This spread sheet allows the user to input the certified distances between pillars and based on the number of pillars used determine the accuracy of the different pillar combinations. The additive constant and scale factor error can be calculated along with the standard deviation of these results. Taking into account the uncertainty of values of the baseline from the regulation 13 certificate, these can calculated at a 95% confidence interval.

3.4 Observations

Observations will be carried out over the Caboolture EDM baseline. Only one set of observations will be taken for each instrument. By only taking the one set of observations the comparison between the different baseline designs will be more accurate as there will be fewer variables changing such as temperature and pressure.

These observations will help to indicate whether using modern day instruments will result in fewer pillars being needed to be used for the calibration of EDME.

3.4.1 Instruments

Three total stations will be used to carry out the observations over the Caboolture EDME baseline. The three instruments will be:

- Topcon ES 103. This is a 3" instrument with a distance measurement accuracy of 2mm +- 2ppm;
- Leica Viva TS15. This is a 1" instrument with a distance measurement accuracy of 1mm +- 1.5ppm and
- Nikon NPR-362. This is a 3" instrument with a distance measurement accuracy of 2mm +- 2ppm.

As previously noted, the Caboolture EDM range is designed for instruments with a unit length of 10m, to account for cyclic error. However, as modern instruments commonly have a unit length of approximately 1m this is an aspect of the range that becomes redundant when redesigning it.

Figure 3.4 demonstrates the distance modulo for a unit length of 1m for the Caboolture EDM baseline. The 21 baselines are evenly distributed and there is less than 0.1m difference between any two of the baseline observations. This helps in showing that the cyclic error is indeed redundant when calibrating EDME.

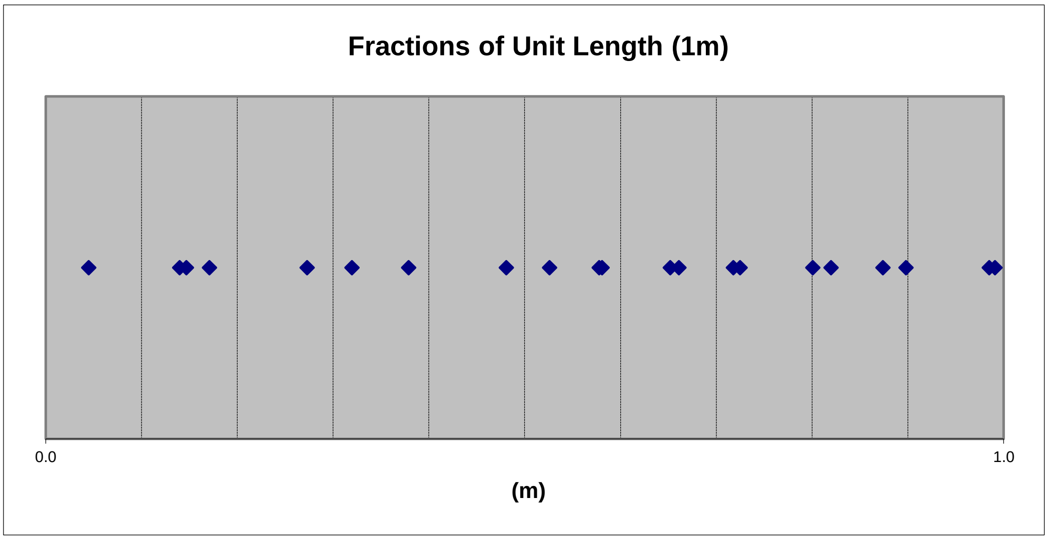


Figure 3.4: Distance modulo of Unit Length of the Caboolture range (1m). Each of the 21 baselines are shown

3.4.2 Observation Sequences

Observations will be taken with each total station over the EDME baseline observing the current 7 pillar system. All observations will be conducted in accordance with LTOLE.

The calibration involves a total of 21 individual baseline observations between the pillars. The order in which the 21 observations are carried out are not crucial DNRM (2012) suggests the most simple and practical pattern is either the forward or reverse run.

The observations will occur in a forward run, whereby the EDM instrument starts at Station 0 and measures to the prism on Station 1. Following this, the prism is moved to Station 2 and so on until the prism has been observed at each pillar (1-6) from pillar 0.

Next, the instrument is moved to Station 1 and the prism is moved in reverse order so that the sequence observed is 1-6, 1-5, 1-4, 1-3, and 1-2. The instrument will then be placed at Station 2, again measuring the prism at each pillar (2-3, 2-4, 2-5 and 2-6).

The observations will continue in this sequence pattern until the last sequence of 5-6 is completed. Figure 3.5 demonstrated the series of observations to be undertaken.

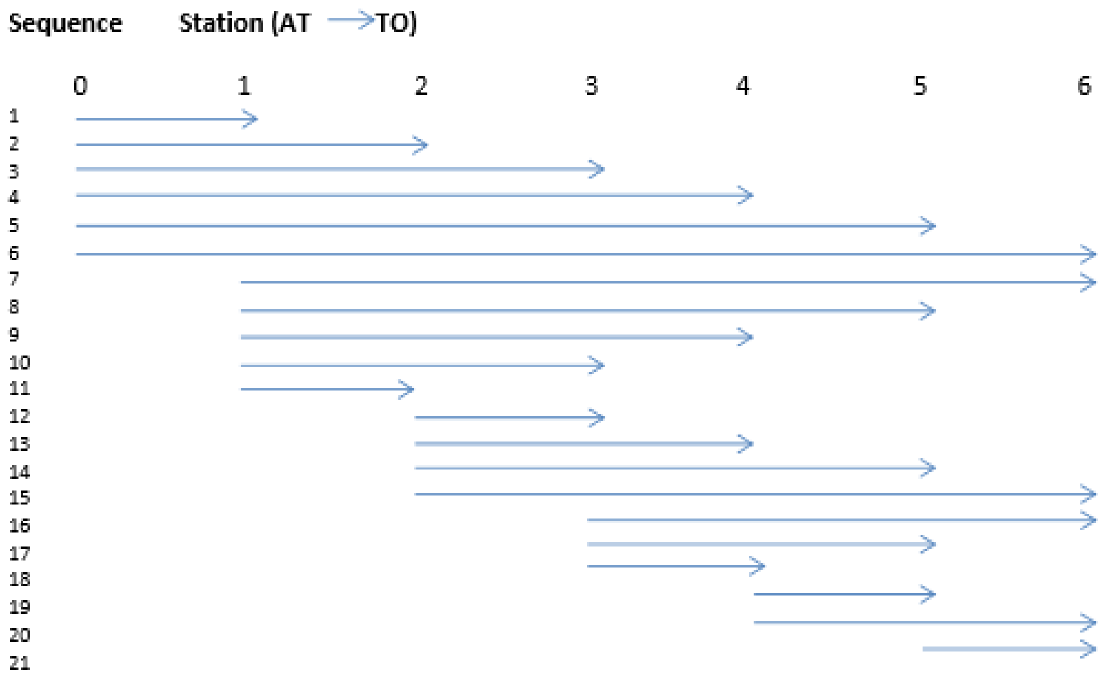


Figure 3.5: Forward Run Sequence Pattern (DNRM, 2012)

As advised by DNRM (2012) a universal target height will be used for all stations.

3.5 Reduction

Two programs will be utilised for the reduction of the three different instruments. Standard software provided by DNRM and a software program (EDM_08) provided by retired Cadastral Surveyor Colin Moorhead. The DNRM software will be utilised throughout the observation reductions where EDM_08 will be used only as a check to verify the results of DNRM software.

Once reduced, the results will provide a report that states the relationship between the measurements made by the instrument used and the certified values from the calibration performed by the Verifying Authority (being the known distances of the baseline). From this, the correction that is to be applied to the instrument is discovered. The correction (or relationship) is described as a single correction with two parts: zero constant error and scale error. DNRM (2012) states this is expressed in the following way:

$\pm (\chi + y \times 10\text{-}3.L)$ mm (where L is length in m)

Or:

$\pm (\chi \text{ mm} + y \text{ PPM})$

To determine how fewer observations will affect calibration results and the effect of a shorter baseline on determining an accurate scale error, the results of reducing each run will be compared, with the standard seven pillar design as the control.

These alternative baseline methods will address the three errors found in EDME. Because modern day instruments have a smaller wavelength (commonly a unit length of around 1m) any cyclic error can be determined by measuring fewer baselines. The shorter wavelength means fewer modulo distances, the constant error is able to be determined over a very short distance. It is not influenced by how great the inter-pillar distance is, but by the number of inter-pillar distances measured. The scale error is determined over longer distances and should be at least the length of what an average surveyor would usually measure day to day in the field which is not usually more than 700 metres.

3.6 Legal Traceability

The Legal Traceability of length for EDME (LTOLE), EDME Comparison Procedure set out by the department of natural Resources and mines is the departments recommended procedure for carrying out an EDME comparison, in order to achieve legal traceability. All observations carried out in this project will comply with the guidelines outlined in this procedure.

These procedures cover the setup and inspection of the pillars and baseline itself and details observation requirements. Accordingly, and as described above, a total of 21 interstation observations will be carried out and all will be made to one prism only.

Chapter 4: Analysis of Data and Results

4.1 Introduction

The aim of this chapter is to determine the three alternative baseline designs by calculating the most accurate pillar combinations for the 4, 5 and 6 pillar baselines over the Caboolture EDM baseline.

Once these pillar combinations have been determined, the field observations will be reduced and comparisons will be drawn between the standard seven pillar method and the proposed alternative pillar baselines.

A brief analysis of the results will be undertaken and one of the three baseline designs will be chosen based on the key characteristics mentioned in Chapter 3. The chosen baseline will then be further analysed and alterations may be made to the design to achieve a positive balance of the key characteristics.

4.2 Baseline Design combinations

Table 4.1 shows the different four pillar combinations along with their respective index constant error, scale error and uncertainties at a 95% confidence interval. As previously noted in Chapter 3, these results were simulated by utilising a least squares adjustment spreadsheet provided by Bruce Harvey from the University of New South Wales.

It can be seen from the results in Table 4.1 that the use of the pillar combinations 0, 1, 2 & 6 provides the most accurate baseline. This pillar combination will be adopted as the alternative baseline design for 4 pillars and will be utilised for all reductions.

4 Pillar Combinations	Index Constant	Index Constant (Uncertainty 95%)	Scale error	Scale Factor (Uncertainty 95%)
0,1,2,3	0.6 mm	+-1.6 mm	2.8 ppm	+- 7.9 ppm
0,1,2,5	0.5mm	+-1.3 mm	1.6 ppm	+- 4.5ppm
0,1,2,6	0.4 mm	+-1.2 mm	1.2 ppm	+- 3.3 ppm
0,4,5,6	0.9 mm	+-2.5 mm	1.8 ppm	+- 4.9ppm
0,1,5,6	0.6 mm	+-1.7 mm	1.2 ppm	+- 3.4 ppm
0,2,3,6	0.7 mm	+-1.9 mm	1.5 ppm	+-4.2ppm

Table 4.1: 4 Pillar combinations

Table 4.2 shows the different pillar combinations that were simulated when using 5 pillars. The results show that the most accurate baseline is determined by the use of the pillar combination 0, 1, 2, 5 & 6. This pillar combination will be adopted as the alternative baseline design for 5 pillars and will be used for all reductions.

5 Pillar Combinations	Index Constant	Index Constant (Uncertainty 95%)	Scale error	Scale Factor (Uncertainty 95%)
0,1,2,3,4	0.5 mm	+-1.1 mm	1.8 ppm	+- 4.2 ppm
0,1,2,4,5	0.4 mm	+-1.0 mm	1.4 ppm	+- 3.2 ppm
0,1,2,3,5	0.5 mm	+-1.1 mm	1.5 ppm	+- 3.5 ppm
0,1,2,5,6	0.4 mm	+-1.0 mm	1.0 ppm	+- 2.3 ppm
0,1,2,3,6	0.4 mm	+-0.9 mm	1.1 ppm	+- 2.5 ppm
0,3,4,5,6	0.6 mm	+-1.4 mm	1.4 ppm	+- 3.2 ppm

Table 4.2: 5 Pillar combinations

Table 4.3 shows the different pillar combinations that were simulated when using 6 pillars. The results below for the different pillar combinations are very similar and show little variation in accuracy. Pillar combination 0, 1, 2, 3, 4 & 6 has been chosen as the alternative baseline design for 6 pillars. This is due to this combination achieving the most accurate index constant and 2nd most accurate scale factor error. This pillar combination will be adopted as the alternative baseline design for 6 pillars and will be utilised for all reductions.

6 Pillar Combinations	Index Constant	Index Constant (Uncertainty 95%)	Scale error	Scale Factor (Uncertainty 95%)
0,1,2,3,4,5	0.4 mm	+-0.9 mm	1.3 ppm	+- 2.8 ppm
0,1,2,4,5,6	0.4 mm	+-0.9 mm	0.9 ppm	+- 2.0 ppm
0,1,2,3,4,6	0.4 mm	+-0.8 mm	1.0 ppm	+- 2.1 ppm

Table 4.3: 6 Pillar combinations

The three alternative pillar designs (as outlined in the preceding paragraphs) have been chosen ensuring that they are the most accurate combination of pillars for each individual design. The above results demonstrate that in order to achieve the most accurate combination of pillars there has ta mixture of short distances (to aid with zero constant error) and long distances (to aid with scale error) are required.

4.3 Reduction and Results

After the field observations had been carried out, the data was reduced for each of the pillar combinations. The standard seven pillar combination was the first reduction to be performed using the standard DNRM software in addition to EDM_08 to verify the DNRM software. Following this, the alternative 4, 5, 6 baselines designs were reduced and compared to the standard 7 pillar results.

Reductions using TOPCON ES 103

The first instrument that was reduced was the Topcon ES 103. The DNRM software was tested against the EDM 08 program using the 7 pillars and the results were:

- Index constant: 3.7 mm
- Scale Factor: 3.9 ppm
- Standard Deviation 1.8mm

The results are similar from each of the different programs which verify the DNRM software. See Appendix Q for full results using the EDM 08 software.

Number of Pillars	Index Constant	Index Constant (Uncertainty 95%)	Scale Factor	Scale Factor (Uncertainty 95%)
7 Pillar	-3.56mm	+- 1.17 mm	-3.35 ppm	+- 2.65 ppm
6 Pillar	-3.76 mm	+- 1.15 mm	-3.07 ppm	+- 2.64 ppm
5 Pillar	-3.62 mm	+- 1.93 mm	-3.44 ppm	+- 3.80 ppm
4 pillar	-2.09 mm	+- 3.00 mm	-6.06 ppm	+- 5.07 ppm

Table 4.4: Results of the Topcon ES 103

In Table 4.4 the index constant and scale factor correction to be applied to the instrument for pillars 7, 6 and 5 are all very similar. Only a 0.20mm difference in the index constant and a 0.37 ppm difference in the scale factor error exist. Additionally, the uncertainty of each of the errors does not vary significantly between these different pillar combinations.

Comparing the 4 pillar observations to the 7 pillar baseline shows there is a much larger difference. There is a 1.67mm difference for the index constant and 2.99 ppm difference for the scale factor. The uncertainty of each of the errors also starts to vary substantially when using the 4 pillars design in comparison to the 7 pillar design. See Appendix C-F for the certificate of results.

The 4 pillar design remains in the range required by the minimum standards of the uncertainty of calibration of an EDM instrument, being 4.0mm +/- 20 ppm. This achieves a reasonably accurate result and falls well within the minimum standards set by the Working Party of the National Standards Commission of the calibration of EDM equipment of 1 February, 1983.

Reductions using NIKON NPR-362

The second instrument reduced was the Nikon NPR-362. The DNRM software was again tested against the EDM 08 program using the 7 pillars and the results were:

- Index constant: -1.3 mm
- Scale Factor: 2.0 ppm
- Standard Deviation 1.3mm

The results are similar from each of the different programs which verify the DNRM software. See Appendix R for full results using the EDM 08 software.

Number of Pillars	Index Constant	Index Constant (Uncertainty 95%)	Scale Factor	Scale Factor (Uncertainty 95%)
7 Pillar	-0.90mm	+- 1.00 mm	-1.88 ppm	+- 2.00 ppm
6 Pillar	-0.79 mm	+- 1.00 mm	-1.60 ppm	+- 2.00 ppm
5 Pillar	-0.66 mm	+- 1.31 mm	-2.30 ppm	+- 2.57 ppm
4 pillar	-0.34 mm	+- 2.26 mm	-2.0 ppm	+- 3.82 ppm

Table 4.5: Results of the Nikon NPR-362

Table 4.5 demonstrates that the Index constant and scale factor correction to be applied to the instrument are all very similar for pillars 7, 6 and 5 and 4. There is only a 0.66mm difference in the index constant and a 0.42 ppm in the scale factor error.

However, when comparing the uncertainty values for the index constant and scale factor a similar result to the Topcon ES103 is achieved. The uncertainty at a 95% confidence interval is increased when comparing the 4 pillar design to the 7 pillar. The 5 and 6 pillar designs are significantly more accurate than the 4 pillar which agrees with the Topcon results. See Appendix G-J for the certificate of results.

Reductions using LEICA TS-15

The third and last instrument that was reduced was the Leica TS15. The DNRM software was again tested against the EDM 08 program and the results were index constant: 3.6mm and scale factor was 0.2 ppm with a standard deviation of 1.2mm See appendix S For the full results. This again verifies the DNRM software.

Number of Pillars	Index Constant	Index Constant (Uncertainty 95%)	Scale Factor	Scale Factor (Uncertainty 95%)
7 Pillar	-3.25 mm	+- 1.0 mm	0.43 ppm	+- 2.0 ppm
6 Pillar	-3.24 mm	+- 1.0 mm	0.98 ppm	+- 2.0 ppm
5 Pillar	-3.43 mm	+- 1.14 mm	0.43 ppm	+- 2.25 ppm
4 pillar	-2.81 mm	+- 2.01 mm	-0.65 ppm	+- 3.40 ppm

Table 4.6: Results of the Leica Viva TS15

Table 4.6 demonstrates that the index constant and scale factor correction to be applied to the instrument are very similar for pillars 7, 6, 5 and 4. There is only a 0.62 mm difference in the index constant and a 1.53 ppm in the scale factor error.

As seen with the other two instruments previously tested, when comparing the 4 pillar design to the 7 pillar the uncertainty at 95% increases dramatically compared to the 5 and 6 pillar designs. See Appendix K-N for the certificate of results.

Summary of Reductions

All of the instruments have been reduced and the results tabulated. An obvious pattern emerges between the current 7 pillar design and the three alternative designs. The index constant and scale factor generally does not vary much between the different pillar designs and instruments. The uncertainty values on the other hand do vary, especially between the 4 pillar design and the 7 pillar. This will be investigated in more detail.

Figure 4.1 below shows the different instruments and there corresponding index constant uncertainty at a 95% confidence interval. It can be seen from the graph that it is most accurate using the current 7 pillar design. This being said the alternative designs for 6 and 5 pillars are also very accurate and only differ from the 7 pillar design by 0-0.8mm. It can also be seen that the four pillar design for every instrument increases in uncertainty and can vary up to 2.0 mm when compared to the 7 pillar design.

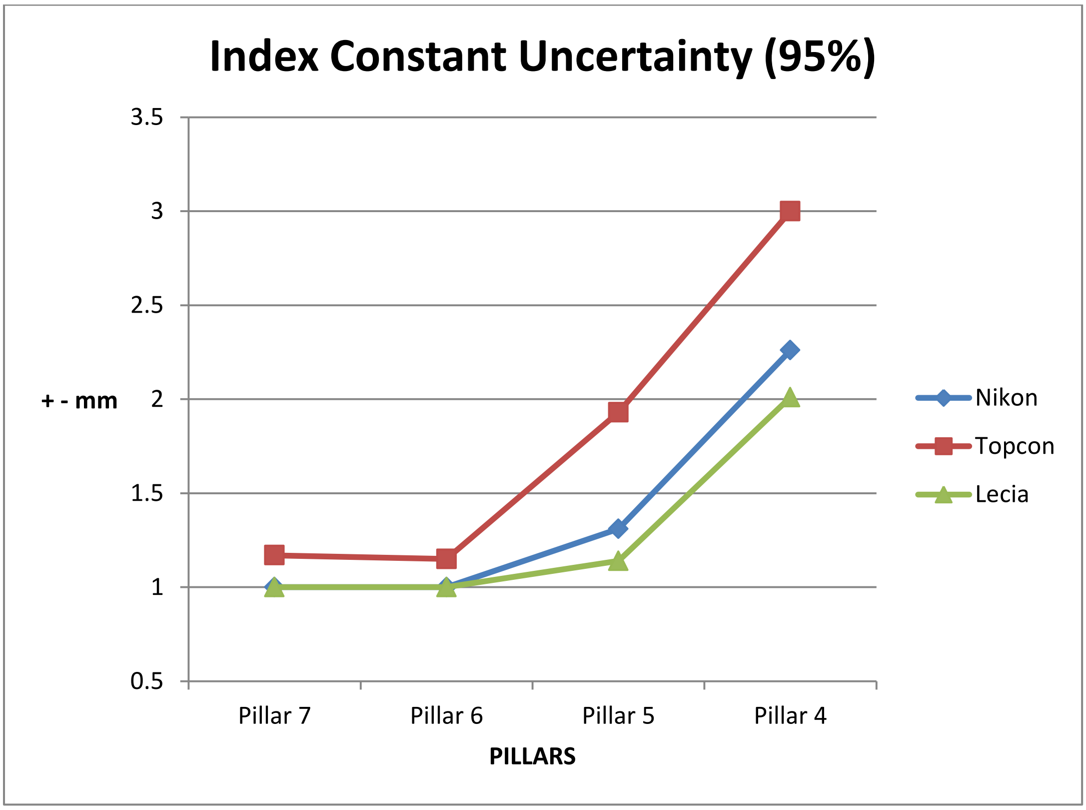


Figure 4.1: Index Constant Uncertainty (95%)

Figure 4.2 below shows the different instruments and there corresponding scale uncertainty at a 95% confidence interval. It is noted that the graph is very similar in shape to figure 4.1 showing the index constant uncertainty.

This demonstrates that the 7 pillar baseline is the most accurate and that the uncertainties slightly increase as the pillars decrease. As seen in Figure 4.1 the 5 & 6 pillar baseline designs are still very accurate and only differ from the 7 pillar design by 0-1.7 ppm. To demonstrate this in a practical sense for every 1000 metres measured there is a 1.7 mm uncertainty. It can be seen that all instruments in the four pillar design increase in uncertainty.

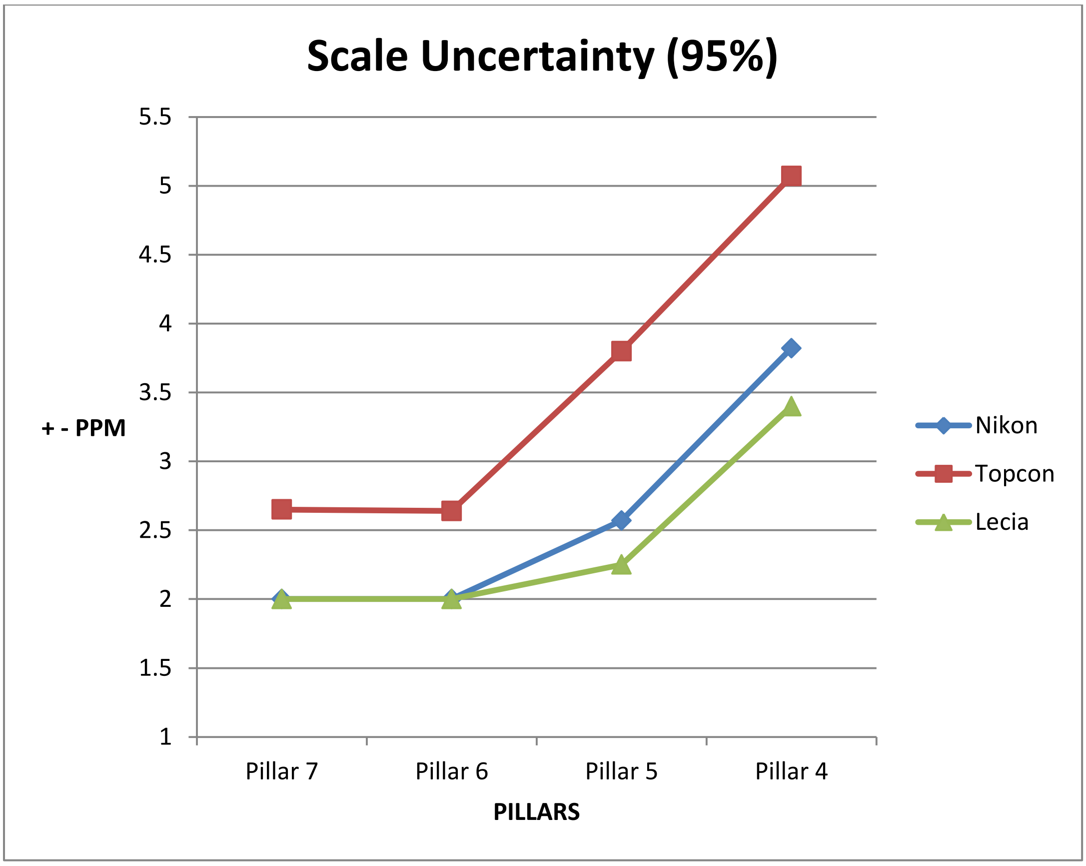


Figure 4.2: Scale Factor Uncertainty (95%)

The above results indicate that all three of the proposed alternative baseline designs fall well within the minimum standards set down for the calibration of EDME. It is important to note that this guideline is now 32 years old and has therefore not evolved to consider or account for advances in technology.

The results show that there is a significant decrease in accuracy from the 5 pillar design to the 4 pillar design. It is concluded that the 4 pillar design is not sufficiently accurate and does not satisfy one of the key characteristics of the alternative baseline. The high uncertainty of the 4 pillar design is due to only 6 individual baselines being measured, resulting in a minimal amount of redundancies.

4.4 Adjustments to 5 Pillar Design.

The 5 pillar design provided positive results and certainly demonstrated its advantages over the current 7 pillar baseline. The 5 pillar design will be more efficient for surveyors and be more economical to install and maintain. One main characteristic the 5 pillar baselines did not achieve was to result in a shorter distance to allow for easier installation in populated areas where space is an issue.

The 5 pillar design will be altered so that it is an overall distance of 714 metres as opposed to 1148 metres. Shortening the baseline will cause an increase in the uncertainty of the baseline design which will be investigated below. Consequentially, the shorter distance will be easier to install in more locations, achieving a key objective of an alternative baseline.

The average surveyor conducting work generally will not measure a distance of more than 700m. Therefore, there is little benefit in calibrating instruments over these longer distances.

The 5 pillar design is manipulated to decrease its length to approximately 700m. The results of this manipulated 5 pillar design are then compared to the results of the original 5 pillar design. This process will then be repeated using pillars 0,1,2,4, & 5. The accuracy of this pillar combination is outlined in Table 4.7. This new baseline will now be reduced and compared to the original 5 pillar design to see whether the accuracy is compromised to allow the benefit of the shorter distance baseline.

0,1,2,4,5	0.4 mm	+-1.0 mm	1.4 ppm	+- 3.2 ppm
0,1,2,5,6	0.4 mm	+-1.0 mm	1.0 ppm	+- 2.3 ppm

Table 4.7: Comparison between old and new 5 pillar designs.

Reductions using Topcon ES-103

Table 4.8 shows the Comparison between old and new 5 pillar designs for the Topcon ES-103. See Appendix O for the certificate of the results.

Number of Pillars	Index Constant	Index Constant (Uncertainty 95%)	Scale Factor	Scale Factor (Uncertainty 95%)
7 Pillar	-3.56mm	+- 1.17 mm	-3.35 ppm	+- 2.65 ppm
5 Pillar	-3.62 mm	+- 1.93 mm	-3.44 ppm	+- 3.80 ppm
5 pillar Alt	-3.36 mm	+- 1.13 mm	-5.68 ppm	+- 3.05 ppm

Table 4.8: Topcon comparisons between old and new 5 pillar designs.

Reductions using Nikon NPR-362

Table 4.8 shows the Comparison between old and new 5 pillar designs for the Nikon NPR-362. See Appendix P for the certificate of the results.

Number of Pillars	Index Constant	Index Constant (Uncertainty 95%)	Scale Factor	Scale Factor (Uncertainty 95%)
7 Pillar	-0.90mm	+- 1.00 mm	-1.88 ppm	+- 2.00 ppm
5 Pillar	-0.66 mm	+- 1.31 mm	-2.30 ppm	+- 2.57 ppm
5 Pillar Alt	-0.26 mm	+- 1.01 mm	-5.04 ppm	+- 2.92 ppm

Table 4.9: Nikon comparisons between old and new 5 pillar designs.

Reductions using Leica TS-15

Table 4.10 shows the Comparison between old and new 5 pillar designs for the Leica TS-15.

Number of Pillars	Index Constant	Index Constant (Uncertainty 95%)	Scale Factor	Scale Factor (Uncertainty 95%)
7 Pillar	-3.25 mm	+- 1.0 mm	0.43 ppm	+- 2.0 ppm
5 Pillar	-3.43 mm	+- 1.14 mm	0.43 ppm	+- 2.25 ppm
5 Pillar Alt	-3.12 mm	+- 1.00mm	-1.26 ppm	+- 2.05 ppm

Table 4.10: Comparison between old and new 5 pillar designs.

It can be seen from the above tables that the new altered 5 pillar design is as accurate as the first 5 pillar design. The new 5 pillar design shows that it is possible to decrease the amount of pillars and length of the range while still keeping the accuracy and legal traceability.

Chapter 5 – Discussion and Conclusions

5.1 Introduction

The results in chapter 4 provide an in depth review of the proposed baselines and draws a comparison with the current standard 7 pillar baselines. It shows the importance of which combination of pillars should be used. These observations have revealed significant results that require in depth analysis to determine what is ultimately the most desirable alternative baseline design for the calibration of EDME.

This Chapter will analyse those results to finally determine the viability, accuracy and value of the proposed alternative baseline.

With the rapid advances in EDME technology and the fact that current calibration baselines throughout Queensland were designed for instruments from two decades ago, it is a logical conclusion that the current baselines are outdated and do not specifically cater to the modern day instrument.

This Project successfully demonstrates that a considered and carefully selected combination of pillars set at certain distances apart, high accuracies can be achieved using only 5 pillars and not the current 7 pillar method. This will allow modern day instruments to potentially be calibrated over the current 7 pillars in around a third of the time. Using a 5 pillar design, only 10 baselines are required to be measured. This results in a total of 100 shots being taken in comparison to 21 baselines and 210 shots taken with the current 7 pillar method.

The literature review revealed that baselines should ideally be approximately one kilometre in length in order to address the scale error in instruments. The results do support this motion but the decreasing the range to around 700 metres does not affect the accuracy of the scale error by very much. It also must be noted that most surveyors will not measure distances of more than 600 metres on an average day. By decreasing the overall distance of the baseline this will allow for the erection of more baselines in highly populated areas.

It has to be remembered that the final 5 pillar design will not be the same design for all EDM baselines. The final pillar combination is specific to the Caboolture EDM range and will be different for all baselines.

Chapter 6 – Future Work

With the advances in technology and the increasing accuracy of EDME it will only be a matter of time until the equipment is so accurate that the calibration baselines are no longer required.

It is suggested that further research be conducted into the accuracy of the different pillar setups and the errors inherit within these setups. Such research should account for the movement of the concrete pillars. It is likely that such a consideration will largely impact the accuracy of the baseline and therefore a valuable subject of future work, but outside the scope of this project.

This dissertation has critically analysed modern day EDME and the errors that are associated with these instruments. It has investigated different types of calibration baselines and has designed and tested alternative baselines. From the results gathered an alternative baseline has been proposed but it has not yet investigated possible suitable locations for this alternative baseline.

Further work might investigate potential sites in and around Brisbane city to assist city surveyors to calibrate their instruments. Investigating potential sites will involve:

- Underground services locations
- Soil testing for stability
- Line of site between all the pillars
- Suitable land tenure

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Appendix A

ENG 4111/4112 Research Project
Project Specification

FOR: Rhys Pescod

TOPIC: Design of Electronic Distance Measurement Equipment (EDME)

SUPERVISORS: Dr Glenn Campbell (USQ Supervisor)

ENROLMENT: ENG 4111 – S1 2015
ENG 4112 – S2 2015

PROJECT AIM: This project seeks to investigate whether the current method of EDME calibration is still necessary and to see if the design of the baselines can be modified due to changes in technology.

PROGRAMME:

1. Research the history and background of EDME design and calibrations.
2. Establish the origins and design criteria for the current 7 pillar method.
3. Research alternative calibration methods that have been used in Australia and overseas.
4. Investigate the design and construction of current EDME, both time of flight and phase shift.
5. Design a more efficient and shorter EDME calibration technique.
6. Incorporate a method to estimate horizontal and vertical collimation errors within the new design.
7. Compare the new EDME calibration technique to a current 7 Pillar Baseline.
8. Analyse and prepare findings
9. Prepare and submit a project dissertation.

Appendix B

Each line measured one way only, or mean distances entered:									
D1		0.0000	Fixed						
D2		64.8740	Fixed						
D3		181.1470	Fixed						
D4		398.7250	Fixed						
D5		1148.5260	Fixed						
Starting values of Parameters:									
Additive Constant		0.00	mm		0	m			
Scale Factor		0.00	ppm		0	factor			
Std dev of dists		0.5	mm +	1.3	ppm				
Measurements:								Residuals	
From	To	Obs dist (m)	Known dist	s (mm)	**Partials A/s**		b/s	v mm	v/s
1	2	64.8740	64.8740	0.6	-1.7	-0.11	0.0	0.0	0.0
1	3	181.1470	181.1470	0.7	-1.4	-0.25	0.0	0.0	0.0
1	4	398.7250	398.7250	1.0	-1.0	-0.39	0.0	0.0	0.0
1	5	1148.5260	1148.5260	2.0	-0.5	-0.58	0.0	0.0	0.0
2	3	116.2730	116.2730	0.7	-1.5	-0.18	0.0	0.0	0.0
2	4	333.8510	333.8510	0.9	-1.1	-0.36	0.0	0.0	0.0
2	5	1083.6520	1083.6520	1.9	-0.5	-0.57	0.0	0.0	0.0
3	4	217.5780	217.5780	0.8	-1.3	-0.28	0.0	0.0	0.0
3	5	967.3790	967.3790	1.8	-0.6	-0.55	0.0	0.0	0.0
4	5	749.8010	749.8010	1.5	-0.7	-0.51	0.0	0.0	0.0
	n:	10							
degrees freedom:		8						Variance Factor	0.0
	N-1	0.16	-0.30		dx	0.00			
		-0.30	1.17			0.00			
		Adj parameters		std dev		95% CI +/-			
	AC	0.00	mm	0.4	mm	0.9	Correlation between AC and SF		
	SF	0.00	ppm	1.1	ppm	2.5	-0.70		
Application of parameters:			654.321	Measured					
			654.3210	Corrected					

Appendix C

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 12/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 2:58:52 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Topcon
EDM Instrument Model: ES103
EDM Serial Number: BR0236

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE
Authority: DNRM
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

Location: Dances Rd
Last calibration Date: 28/08/2013

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.56 - 0.00335 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.56 mm	± 1.17 mm
Scale	-3.35 ppm	± 2.65 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.17 mm + 2.65 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.30	±5.00	PASS
100	±1.43	±6.00	PASS
300	±1.96	±10.00	PASS
500	±2.49	±14.00	PASS
800	±3.29	±20.00	PASS
1100	±4.09	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………….....

Results checked by: …………………….

Position: ………………………………………

Position: ………………………………...

Signature: ……………………………………

Approved Signatory: ……………………

Date: …………………………………………

Date: ……………………………………..

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Appendix D

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 12/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 3:14:09 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Topcon
EDM Instrument Model: ES103
EDM Serial Number: BR0236

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.76 - 0.00307 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.76 mm	± 1.15 mm
Scale	-3.07 ppm	± 2.64 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.15 mm + 2.64 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.30	±5.00	PASS
100	±1.43	±6.00	PASS
300	±1.96	±10.00	PASS
500	±2.49	±14.00	PASS
800	±3.29	±20.00	PASS
1100	±4.09	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ………………………………..... Results checked by: …………………….

Position: ……………………………………… Position: ………………………………...

Signature: …………………………………… Approved Signatory: ……………………

Date: ………………………………………… Date: ……………………………………..

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Appendix E

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 12/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 3:41:15 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Topcon
EDM Instrument Model: ES103
EDM Serial Number: BR0236

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.62 - 0.00344 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.62 mm	± 1.93 mm
Scale	-3.44 ppm	± 3.80 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.93 mm + 3.80 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±2.12	±5.00	PASS
100	±2.31	±6.00	PASS
300	±3.07	±10.00	PASS
500	±3.83	±14.00	PASS
800	±4.97	±20.00	PASS
1100	±6.11	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………….....

Position: ………………………………………

Signature: ……………………………………

Date: …………………………………………

Results checked by: …………………….

Position: ………………………………...

Approved Signatory: ……………………

Date: ……………………………………..

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Appendix F

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 12/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 4:02:54 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Topcon
EDM Instrument Model: ES103
EDM Serial Number: BR0236

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -2.09 - 0.00606 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-2.09 mm	± 3.00 mm
Scale	-3.16 ppm	± 5.07 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.58 mm + 3.34 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±3.26	±5.00	PASS
100	±3.51	±6.00	PASS
300	±4.53	±10.00	PASS
500	±5.54	±14.00	PASS
800	±7.06	±20.00	PASS
1100	±8.58	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: …………………………….....

Position: ………………………………………

Signature: ……………………………………

Date: …………………………………………

Results checked by: …………………….

Position: ………………………………...

Approved Signatory: ……………………

Date: ……………………………………..

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Appendix G

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 13/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 3:31:54 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Nikon
EDM Instrument Model: NPR-362
EDM Serial Number: 030031

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -0.90 - 0.00188 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-0.90 mm	± 1.00 mm
Scale	-1.88ppm	± 2.00 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.00 mm + 2.00 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.10	±5.00	PASS
100	±1.20	±6.00	PASS
300	±1.60	±10.00	PASS
500	±2.00	±14.00	PASS
800	±2.60	±20.00	PASS
1100	±3.20	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………….....

Results checked by: …………………….

Position: ………………………………………

Position: ………………………………...

Signature: ……………………………………

Approved Signatory: ……………………

Date: …………………………………………

Date: ……………………………………..

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Appendix H

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015
Instrument Operator: Rhys Pescod
Computation Date: 13/08/2015
Computation Time: 3:38:44 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Nikon
EDM Instrument Model: NPR-362
EDM Serial Number: 030031

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE
Authority: DNRM
Location: Dances Rd
Last calibration Date: 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -0.79 - 0.00160 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-0.79 mm	± 1.00 mm
Scale	-1.60ppm	± 2.00 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.00 mm + 2.00 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.10	±5.00	PASS
100	±1.20	±6.00	PASS
300	±1.60	±10.00	PASS
500	±2.00	±14.00	PASS
800	±2.60	±20.00	PASS
1100	±3.20	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: …………………………….....

Results checked by: …………………….

Position: ………………………………………

Position: ………………………………...

Signature: ……………………………………

Approved Signatory: ……………………

Date: …………………………………………

Date: ……………………………………..

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Appendix I

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 13/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 3:51:51 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Nikon
EDM Instrument Model: NPR-362
EDM Serial Number: 030031

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -0.66 - 0.00230 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-0.66 mm	± 1.31 mm
Scale	-2.30ppm	± 2.57 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.31 mm + 2.57 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.44	±5.00	PASS
100	±1.56	±6.00	PASS
300	±2.08	±10.00	PASS
500	±2.59	±14.00	PASS
800	±3.36	±20.00	PASS
1100	±4.13	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………..... Results checked by: …………………….

Position: ……………………………………… Position: ………………………………...

Signature: …………………………………… Approved Signatory: ……………………

Date: ………………………………………… Date: ……………………………………..

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Appendix J

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 13/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 4:14:19 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Nikon
EDM Instrument Model: NPR-362
EDM Serial Number: 030031

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -0.34 - 0.00248 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-0.34 mm	± 2.26 mm
Scale	-2.48ppm	± 3.82 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (2.26 mm + 3.82 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.44	±5.00	PASS
100	±1.56	±6.00	PASS
300	±2.08	±10.00	PASS
500	±2.59	±14.00	PASS
800	±3.36	±20.00	PASS
1100	±4.13	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………..... Results checked by: …………………….

Position: ……………………………………… Position: ………………………………...

Signature: …………………………………… Approved Signatory: ……………………

Date: ………………………………………… Date: ……………………………………..

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Appendix K

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 14/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 2:20:41 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Leica
EDM Instrument Model: TS-15
EDM Serial Number: 360168

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.25- 0.00043 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.25 mm	± 1.00 mm
Scale	-0.43ppm	± 2.00 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.00 mm + 2.00 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.10	±5.00	PASS
100	±1.20	±6.00	PASS
300	±1.60	±10.00	PASS
500	±2.00	±14.00	PASS
800	±2.60	±20.00	PASS
1100	±3.20	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: …………………………….....

Results checked by: …………………….

Position: ………………………………………

Position: ………………………………...

Signature: ……………………………………

Approved Signatory: ……………………

Date: …………………………………………

Date: ……………………………………..

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Appendix L

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 14/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 2:44:18 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Leica
EDM Instrument Model: TS-15
EDM Serial Number: 360168

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE
Authority: DNRM
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

Location: Dances Rd
Last calibration Date: 28/08/2013

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.24- 0.00098 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.24 mm	± 1.00 mm
Scale	-0.98ppm	± 2.00 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.00 mm + 2.00 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.10	±5.00	PASS
100	±1.20	±6.00	PASS
300	±1.60	±10.00	PASS
500	±2.00	±14.00	PASS
800	±2.60	±20.00	PASS
1100	±3.20	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………….....

Results checked by: …………………….

Position: ………………………………………

Position: ………………………………...

Signature: ……………………………………

Approved Signatory: ……………………

Date: …………………………………………

Date: ……………………………………..

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Appendix M

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 14/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 3:11:30 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Leica
EDM Instrument Model: TS-15
EDM Serial Number: 360168

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.43- 0.00043 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.43 mm	± 1.14 mm
Scale	-0.43ppm	± 2.25 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.14mm + 2.25 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.26	±5.00	PASS
100	±1.37	±6.00	PASS
300	±1.82	±10.00	PASS
500	±2.27	±14.00	PASS
800	±2.94	±20.00	PASS
1100	±3.61	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………..... Results checked by: …………………….

Position: ……………………………………… Position: ………………………………...

Signature: …………………………………… Approved Signatory: ……………………

Date: ………………………………………… Date: ……………………………………..

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Appendix N

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 14/08/2015
Instrument Operator: Rhys Pescod **Computation Time:** 3:38:20 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Leica
EDM Instrument Model: TS-15
EDM Serial Number: 360168

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -2.81- 0.00035 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-2.81 mm	± 2.01 mm
Scale	-0.65pm	± 3.40 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.14mm + 2.25 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.26	±5.00	PASS
100	±1.37	±6.00	PASS
300	±1.82	±10.00	PASS
500	±2.27	±14.00	PASS
800	±2.94	±20.00	PASS
1100	±3.61	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: …………………………….....

Position: ………………………………………

Signature: ……………………………………

Date: …………………………………………

Results checked by: …………………….

Position: ………………………………...

Approved Signatory: ……………………

Date: ……………………………………..

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Appendix O

Job Identification: Leica TS-15

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015
Instrument Operator: Rhys Pescod
Computation Date: 12/09/2015
Computation Time: 2:15:20 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Leica
EDM Instrument Model: TS-15
EDM Serial Number: 360168

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE
Authority: DNRM
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510
Location: Dances Rd
Last calibration Date: 28/08/2013

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -3.36- 0.00568 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-3.36 mm	± 1.13 mm
Scale	-0.65pm	± 3.05 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.14mm + 2.25 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.28	±5.00	PASS
100	±1.43	±6.00	PASS
300	±2.04	±10.00	PASS
500	±2.65	±14.00	PASS
800	±3.57	±20.00	PASS
1100	±4.48	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: …………………………….....   Results checked by: …………………….

Position: ………………………………………   Position: ……………………………...

Signature: ……………………………………   Approved Signatory: ……………………

Date: …………………………………………   Date: ……………………………………..

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Appendix P

Job Identification: Nikon NPR-362

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 10/06/2015 **Computation Date:** 12/09/2015
Instrument Operator: Rhys Pescod **Computation Time:** 2:31:40 PM

Equipment Details

Instrument Owner: MBRC
Owner Address: Strathpine Office
EDM Instrument Make: Nikon
EDM Instrument Model: NPR-362
EDM Serial Number: 030031

Reflector Make: Sokkia
Reflector Model: Zero Const
Serial Number:
Reflector Constant: 0 mm

Baseline Details

Name CABOOLTURE **Location:** Dances Rd
Authority: DNRM **Last calibration Date:** 28/08/2013
Authority Address: Level 4, 33 King St, CABOOLTURE, QLD, 4510

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -0.26- 0.00504 L
Where L = distance in metres
The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty (95%)
Index	-0.26 mm	± 1.01 mm
Scale	-5.04 ppm	± 2.92 ppm

The instrument correction has been determined from measurements in the range of 65 to 1149metres

Job Identification: Topcon ES 103

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ± (4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95% confidence level. A coverage factor of 2 has been used for the uncertainty computations.

Uncertainty of instrument correction: ± (1.01mm + 2.92 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±1.15	±5.00	PASS
100	±1.30	±6.00	PASS
300	±1.88	±10.00	PASS
500	±2.47	±14.00	PASS
800	±3.34	±20.00	PASS
1100	±4.22	±26.00	PASS

This instrument satisfies the National Standards Commission standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to DNRM Work Instructions as described
in the latest version of CBD.041230.EDME_Comparison_Procedure.

Data entry by: ……………………………….....

Position: ………………………………………

Signature: ……………………………………

Date: …………………………………………

Results checked by: …………………….

Position: ………………………………...

Approved Signatory: ……………………

Date: ……………………………………..

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APPENDIX Q

Caboolture Calibration Range.

Instrument: Topcon ES 103 Date: 13/9/15
Operator: Rhys Pescod Company: MBRC

Line	Measured	Corrected	Absolute	Residual.
0-1	64.880	64.877	64.874	-.003
0-2	181.156	181.153	181.147	-.006
0-3	398.741	398.732	398.725	-.007
0-4	537.062	537.053	537.045	-.008
0-5	714.885	714.874	714.865	-.009
0-6	1148.548	1148.535	1148.526	-.009
1-2	116.281	116.277	116.273	-.004
1-3	333.868	333.857	333.851	-.006
1-4	472.188	472.178	472.171	-.007
1-5	650.012	649.999	649.991	-.008
1-6	1083.676	1083.662	1083.652	-.010
2-3	217.590	217.582	217.578	-.004
2-4	355.911	355.904	355.898	-.006
2-5	533.734	533.724	533.718	-.006
2-6	967.395	967.384	967.379	-.005
3-4	138.324	138.324	138.320	-.004
3-5	316.148	316.145	316.140	-.005
3-6	749.810	749.805	749.801	-.004
4-5	177.829	177.825	177.820	-.005
4-6	611.490	611.485	611.481	-.004
5-6	433.665	433.662	433.661	-.001

Calibration results using 28.08.2013 values as Absolute.

Zero Const: -.0037 Scale Factor: 0.9999961 (-4ppm.) Std Dev 1.8mm.

To correct a measured distance, multiply by
the Scale factor and add the zero constant.

Residuals after the scale factor has been applied to measured distances.

Line	Residual	Line	Residual	Line	Residual
0-1	0.001	1-3	-.001	2-6	0.003
0-2	-.001	1-4	-.001	3-4	0.001
0-3	-.002	1-5	-.002		

APPENDIX R

Caboolture Calibration Range.

Instrument: Nikon NPR-362   Date: 13/9/15
Operator: Rhys Pescod   Company: MBRC

Line	Measured	Corrected	Absolute	Residual.
0-1	64.877	64.875	64.874	-.001
0-2	181.152	181.149	181.147	-.002
0-3	398.737	398.729	398.725	-.004
0-4	537.057	537.049	537.045	-.004
0-5	714.880	714.869	714.865	-.004
0-6	1148.542	1148.529	1148.526	-.003
1-2	116.277	116.273	116.273	-.000
1-3	333.863	333.852	333.851	-.001
1-4	472.183	472.173	472.171	-.002
1-5	650.009	649.996	649.991	-.005
1-6	1083.669	1083.655	1083.652	-.003
2-3	217.588	217.580	217.578	-.002
2-4	355.907	355.900	355.898	-.002
2-5	533.733	533.722	533.718	-.004
2-6	967.393	967.382	967.379	-.003
3-4	138.322	138.321	138.320	-.001
3-5	316.146	316.142	316.140	-.003
3-6	749.808	749.803	749.801	-.002
4-5	177.827	177.822	177.820	-.002
4-6	611.487	611.482	611.481	-.001
5-6	433.663	433.660	433.661	0.001

Calibration results using 28.08.2013 values as Absolute.

Zero Const: -.0013   Scale Factor: 0.9999980 (-2ppm.)   Std Dev 1.3mm.

To correct a measured distance, multiply by
the Scale factor and add the zero constant.

Residuals after the scale factor has been applied to measured distances.

Line	Residual	Line	Residual	Line	Residual
0-1	0.000	1-3	0.001	2-6	0.000
0-2	-.000	1-4	0.000	3-4	0.000
0-3	-.002	1-5	-.002	3-5	-.001

APPENDIX S

Caboolture Calibration Range.

Instrument: LEICA TS-15 Date: 13/09/15
Operator: Rhys Pescod Company: MBRC

Line	Measured	Corrected	Absolute	Residual.
0-1	64.879	64.877	64.874	-.003
0-2	181.154	181.151	181.147	-.004
0-3	398.738	398.729	398.725	-.004
0-4	537.058	537.049	537.045	-.004
0-5	714.882	714.871	714.865	-.006
0-6	1148.543	1148.530	1148.526	-.004
1-2	116.280	116.276	116.273	-.003
1-3	333.865	333.854	333.851	-.003
1-4	472.185	472.175	472.171	-.004
1-5	650.009	649.996	649.991	-.005
1-6	1083.669	1083.655	1083.652	-.003
2-3	217.590	217.582	217.578	-.004
2-4	355.908	355.901	355.898	-.003
2-5	533.733	533.723	533.718	-.005
2-6	967.392	967.381	967.379	-.002
3-4	138.323	138.322	138.320	-.002
3-5	316.148	316.145	316.140	-.005
3-6	749.808	749.803	749.801	-.002
4-5	177.828	177.824	177.820	-.004
4-6	611.488	611.483	611.481	-.002
5-6	433.665	433.662	433.661	-.001

Calibration results using 28.08.2013 values as Absolute.

Zero Const: -.0036 Scale Factor: 1.0000002 (0ppm.) Std Dev 1.2mm.

To correct a measured distance, multiply by
the Scale factor and add the zero constant.

Residuals after the scale factor has been applied to measured distances.

Line	Residual	Line	Residual	Line	Residual
0-1	0.000	1-3	0.000	2-6	0.001
0-2	-.000	1-4	-.000	3-4	0.001
0-3	-.001	1-5	-.002		