University of Southern Queensland

Faculty of Health, Engineering and Sciences

Effect of environmental surroundings on accuracy and precision of total station measurements

A dissertation submitted by

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Abstract

This thesis investigates the accuracy and precision of total station measurements with the interference of commonly found objects in areas surveys are performed. The objects chosen were that of

- Retro-reflective,
    - Sign
    - Tail light assembly
- Background
    - Water
- Obstructions
    - Glass
    - Expanded mesh
    - Vegetation

Field experiments were designed to test how the accuracy and precision of EDM measurements fared when these objects were in line of sight of reflector. Two total stations were chosen for the testing, these were the

- Trimble 5600
- Trimble S6

The reflectors chosen were the

- TRIMBLE SUPER Prism
- TRIMBLE MT1000 Multitrack 360 Degree Target
- Direct Reflex

The field experiments took place over a range of 6 different stations for retro reflective and obstruction testing. The background interference was tested at only 3 due to geographical limitations.

The findings of field testing were

- When measuring with retroreflective objects near or on line of sight, the Super prism should be measured to, which produced a higher accuracy over the 360 prism.
- A problematic distance of 100-200m when measuring to the 360 prism was found to yield particularly erroneous results with the retroreflective sign providing interference.
- Measurements for water in the background showed conflicting trends between the two instruments but both instruments recorded more accurate results using the super prism over the 360 prism.
- All results with the obstruction test recorded a decrease in accuracy with an increase of distance, - excluding the case of vegetation with the 5600 instrument.
- Glass resulted with the least accurate measurements of the obstruction, with a clear trend showing the closer, the obstruction to the instrument the more error reflected into the measurement.
- The super prism recorded much better results than the 360 prism over the shorter distances (25-200m) and minimal differences between the two stations at 400m and 750m stations.

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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.

Joseph Ford 0061029256

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Chapter 1 Introduction

1.1 Project Aims

This thesis is intended to increase awareness of total station measurements and performance, in regards to their accuracy and precision. With the specific aim, to investigate how accuracy and precision of survey measurements are affected with different levels of interference as well as different types of interference. There will be two parts to this project – a research and an experimental investigation. The research explores background information regarding total stations measurements; study the effects of the obstructions, surroundings and background on distance measured by the total stations

This project investigates the effects of interfering retro- reflection objects, interference caused by obstruction and a potential interference caused in the background. Field experiments are designed to assess these objects and their interference caused. This is completed by comparing the true measurements without interference and the measurements recorded with the interfering object in place. Experiments will consist of several interfering objects (one at a time), at various station distances and the obstructions are also tested at different positions from the total station.

The different types of targets have been chosen for this study are:

- Survey prism,
- 360 prisms
- and reflector-less

The interferences are selected from those commonly found in workplace.

First stage is to conduct background research and field experiments. Once the first stage has been completed, the results are documented and analysed to investigate the effects of selected interferences on the accuracy of the measured distance. Finally, the conclusion is given about an idea of how to measure a distance under any given interference to an acceptable degree of accuracy. This will further identify those interferences that are problematic / have no effect on measurements and a solution to best minimise the errors caused by this interference.

1.2 Objectives

The objectives of this project are

1. Research background information regarding the total stations measurement and recording procedures, and find ideal conditions to achieve the most accurate results.

2. Conducting further research about the effect of the obstructions, surroundings and background on distance measured by the total stations.

3. Design an appropriate field experiment to identify the effects that the surrounding environment and obstructions can have on electronic distance measurements (EDM) as well as to show if there are any particular ranges or instances that this effect is more problematic.

4. Complete field experiments and record data from minimum of two survey instruments.

5. Reduce and analyse the field data from the experiments and present in a tabulated form.

6. Evaluate the effects that each of the different test obstructions and surrounding environments have on EDM readings; and

7. Present outcomes and recommend a method of measuring accurately and reliably without error while the interference still in place.

1.3 Justification

As the use of EDM instruments occurs in changing environments, the problems of constantly dissimilar surrounding are presented. Especially with topographic surveys, the surrounds might also be the object being measured to. This may prove especially problematic as the object will be in the line of sight. Because of this, the area that will be investigated is whether objects in the line of sight have an effect on the accuracy and precision of EDM measurements.

> No matter the job, when determining position, there will be a need to achieve within certain accuracy, whether precise or coarse. The limits of tolerance, concerning the accuracy, in the imminent task differ between projects – depending on the motives. But no matter what the final objective is, there is always a limit of tolerance' (Eriksson M. 2014).

Knowing whether measurements performed under the certain conditions can produce results within those accepted tolerances. For without being able to know the limitations of that measuring system, reliable results within a correctly assessed uncertainty will not be able to be achieved.

The objects to provide interference will be chosen from those commonly in the places total station work is undertaken. Previous instances have been identified in the field where it is suspected of obstruction / reflection causing errors with EDM measurements. An example of this is rebar obstruction causing imprecise readings to the 360 mini prism as well as retro reflective objects interfering with the tracking of the prisms. Errors have been found in the past with the total station losing lock and fixing onto another object that is not of interest. Although this problem has been improved with the introduction of "multi-track" prisms, where LED-diodes emit a signal from the prism at a certain frequency that this instrument is programed to, this only improves the total station fix on the prism. The question occurs then, of the accuracy of such technology, which should be assessed or investigated especially when highly accurate results are essential. Since the signal may reflect upon any surface present in the line of sight between the total station and the target, inaccuracy may easily occur.

Water has also shown to provide a problem in total station readings in previous instances. However in the past cases it is not definitive that the only variable changing is the potential interference. Primary research has indicated that limited investigation into the effects of this problem has been documented.

As new technology is being released, manufacturers claim improvements in accuracy and precision for EDM measurements, it is important to test if these can be trusted and repeated in field conditions and also are these enhancements being relied on in incorrect circumstances? This projects objective is to document those areas that are problematic and produce solutions to them, improving better knowledge of survey procedures and practices.

Chapter 2 Literature Review

2.1 Total Stations

The amalgamation of theodolites and an electronic distance meter have developed into that of the modern total stations. These use electronic transit theodolites combined with the distance meter to measure slope distances from the instrument to that of the desired target. ‘They are hence, two essential surveying instruments in one and when used with other technology such as mapping software are able to deliver the ‘total’ surveying package, from measuring to mapping.’ (Jurovich Surveying, 2015)

With the advancements in technology, the majority of total stations are now robotically controlled. This leads to a number of benefits, such as more efficient working conditions that allows the surveyor to easily move around the jobsites without having to manually aim to targets, also allowing the surveyor a better understanding of what is actually being measured, by having them at the site where measurement is being recorded.

This has been done by having the total station “track” the target through a combination of automatic target recognition and laser technology (or infrared sensors).

2.2 Electronic Distance Measurements

Electronic distance meter (EDM) is the distance measurement method applied in modern total stations. EDM has high accuracy and can measure the distance from the total station to its target within millimetres. The total station emits a signal which is then reflected back by the target. The returned signal is then used to calculate the distance between the instrument and the prism. Use of these prisms along with infrared and laser technology make it possible for robotic total stations to search for and lock onto targets automatically.

2.2.1 Time of Flight

Time of Flight (TOF) techniques calculate range measurements by accurately measuring timing information. This is done by the EDM generating many short infrared or laser light pulses, and then transmitting them through the telescope to the desired target. The signals are reflected off the target and the returned signal is recorded by the total station. The travelling time of each light pulse is then determined. The distance between the target and instrument is calculated by using the velocity of the emitted light source. ‘Each pulse sent by the total station is recorded as a direct distance measurement. Thousands of pulses are sent in a second while the measurement is being taken; a good average value can be achieved relatively quickly’ (Trimble Navigation Limited. (2005)).

2.2.2 Phase Shift

Phase Shift measurement techniques use a laser distance unit based on the phase comparison technique. In this method the EDM transmits a coaxial modulated optical measuring beam. In the case of the S6 and 5600 instruments a visible red laser beam that is reflected back by a prism or scattered by a surface on which the beam is aimed. The difference in phase offset of the transmitted and return signal is then used to compute the distance. Errors are resolved by using multiple modulated wavelengths.

2.2.3 Comparison of the Two Techniques

TOF pulses are more powerful than that of the Phase Shift measurements, thus giving the ability to measure greater distances than the Phase Shift method. The Phase Shift method was previously accepted as the most accurate technique, however Trimble claims by the introduction of the Trimble signal processing method used in the Trimble S6 Dr300+ the variation in accuracy in insignificant. ‘Because the TOF method combines direct pulses with Trimble’s signal processing techniques, it is generally more tolerant of line-of-sight interruptions than the Phase Shift method’ (Trimble Navigation Limited. (2005)).

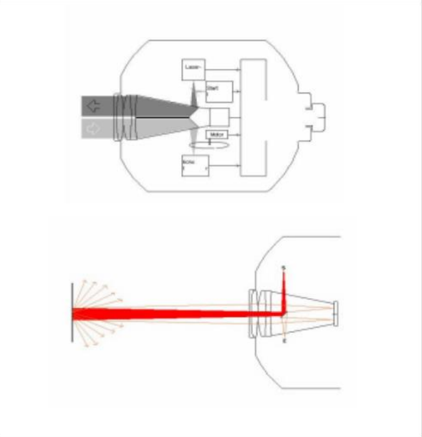


Figure 1. Optical Principles for Time of Flight (Top) and Phase Shift (bottom) EDM (Trimble Navigation limited, (2005)).

2.3 Direct-Reflex EDM Technology

Direct-Reflex (DR) is the latest technology that enables surveyors to measure remote points without having a physical target at those points. As such, DR decreases the number of surveying crew required, increases productivity and enhances personal safety. Integrating Direct-Reflex with robotic technology also opens new possibilities for one-person surveying. DR can be achieved using either of two EDM technology methods: Time of Flight method and the Phase Shift method both of which is used can be by the Trimble series. Each of these methods are designed to suit specific types of needs and applications.

2.4 Measuring objects - 3 Types of Reflection

When measuring to an object, the signal strength is determined on how well the light returns from the target object. For this objects can be categorised into 3 groups, with their reflective qualities being diffuse, specular (mirror-like) or retro-reflective.

2.4.1 Diffuse Reflection

Objects with diffuse qualities are generally those with a rough surface in the terms of the size of the wavelength e.g. wood, concrete, asphalt. The light signal returned still follows the law of reflection, but appears to be scattered as each ray is contacting the surface at different orientations, leading to a dispersed beam. This effect can be seen below, in Figure 2. Diffuse Reflection (Henderson, (2015)).

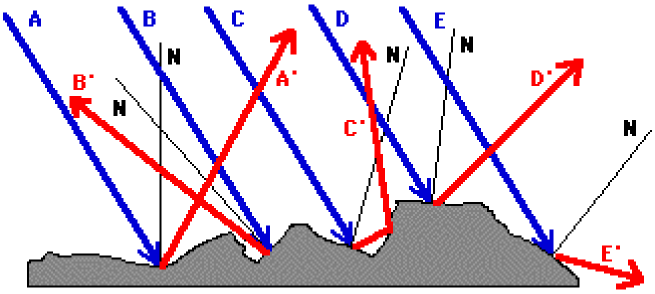


Figure 2. Diffuse Reflection (Henderson, (2015)).

2.4.2 Specular or Mirror-like Reflection

This refers to objects with a flat or smooth surface, for example water or polished metal. These objects act as a mirror reflecting the light beam the same for each ray. the angle of the reflected beam with respect to the targets surface is equal to the angle of incidence. The incident beam and the reflected beam lie in the same plane. This can be seen in Figure 3. Specular Reflection (Riegl, (2002)).

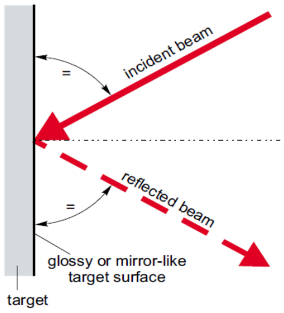


Figure 3. Specular Reflection (Riegl, (2002)).

2.4.3 Retro-Reflection

Retro reflection is when the returned beam is on the same angle as the incidence beam. The same results as perpendicular specular reflection, however with retro reflectors the incidence beam does not need to hit perpendicular. This is the basis as to how a survey prism returns the signal beam without it necessarily being centred perfectly. This action of reflection can be seen below in both retro-reflective objects and survey prisms in Figure 4. Reflection Qualities of a Retro Reflective Object (Riegl, (2002)).and Figure 5. Wave forms entering a prism and being reflected back to the source (Steyn, (2009)). Respectively.

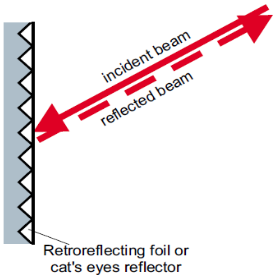


Figure 4. Reflection Qualities of a Retro Reflective Object (Riegl, (2002)).

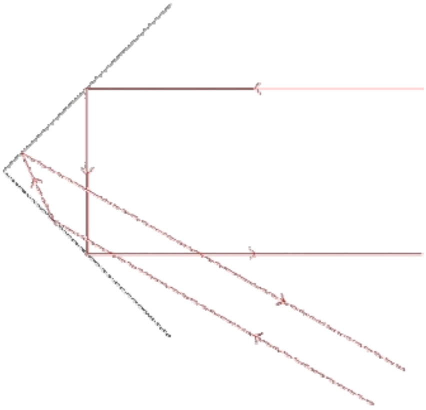


Figure 5. Wave forms entering a prism and being reflected back to the source (Steyn, (2009)).

The use of acrylic or coated retro reflectors has been tested in surveying fields as a means to supply a cheap and reliable Target. These however are also used commonly in urban environments with applications being reflective road signs, cat-eyes, and marker posts. Similar technology is also in certain lighting systems.

An experiment performed by T. J. M. Kennie (1983), testing the maximum range and variation of signal strength returned over distance of retro-reflective materials, found that colour of the reflector appeared to have the most influence with regards to returned signal strength. He found that there is a consistent trend in range performance which closely parallels the visible spectrum, the red reflector giving noticeable more efficient reflection than the amber and so on. (T. J. M. Kennie, 1983). The results can be seen in Figure 6. Reflector performance- return signal strength / distance (T. J. M. Kennie, (1983)).

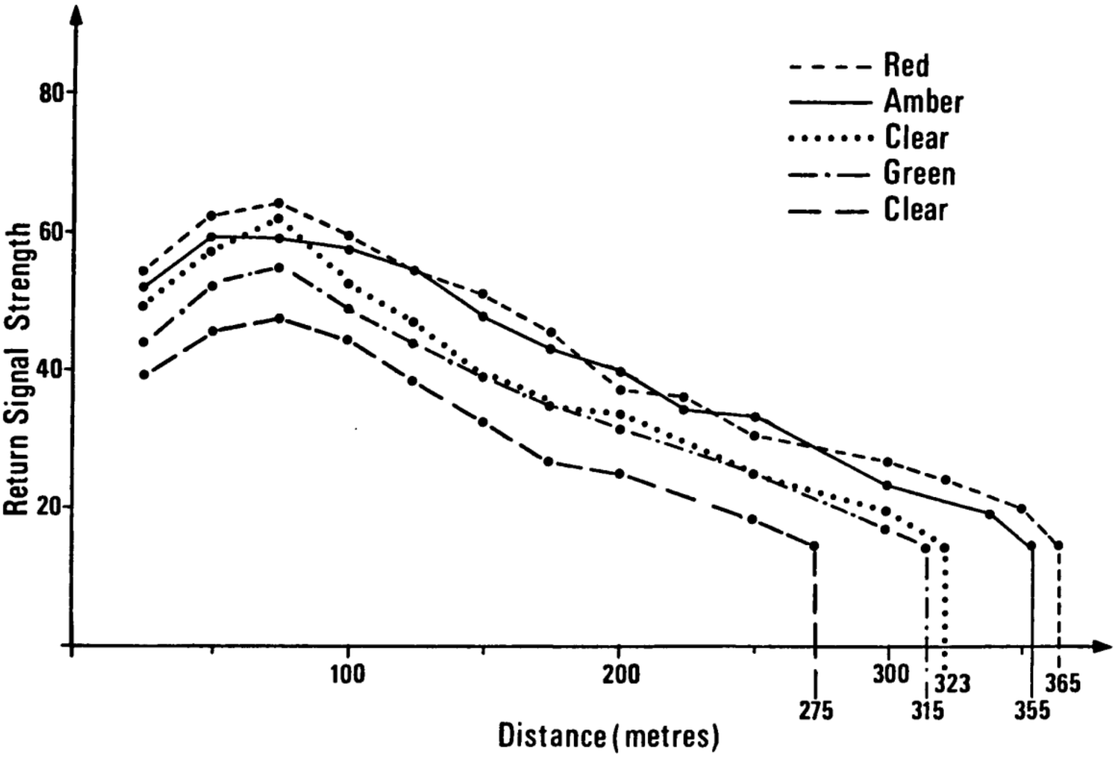


Figure 6. Reflector performance- return signal strength / distance (T. J. M. Kennie, (1983)).

In 1980, Lang’s experiment found similar results. The results were that the four colours of AMERACE reflector tested, the red reflector returned signal 10% better than the orange. This effect was consistent with the other colours (Crystal, green) continuing to decrease by 10% respectively.

2.5 Measuring Conditions and Potential Errors

Leica's guidelines for correct procedures of distance measurements are as follows

Non-Prism measurements

- When a distance measurement is triggered, the EDM measures to the objects which are in the beam path at that moment. If a temporary obstruction, for example a passing vehicle, heavy rain, fog or snow is between the instrument and the point to be measured, the EDM may measure to the obstruction.
- Be sure that the laser beam is not reflected by anything close to the line of sight, for example highly reflective objects.

Prism measurements

- Accurate measurements to prisms should be made in Prism-standard mode.
- Measurements to strongly reflecting targets such as traffic lights in Prism mode without a prism should be avoided. The measured distances may be wrong or inaccurate.
- When a distance measurement is triggered, the EDM measures to the object which is in the beam path at that moment. If for example people, cars, animals, or swaying branches cross the laser beam while a measurement is being taken, a fraction of the laser beam is reflected from these objects and may lead to incorrect distance values.
  (Leica Geosystems AG, (2008))

2.5.1 Beam Divergence

As the laser is directed as a whole (beam) the size of the shape that is projected at a particular distance is known as the beam divergence. This varies for each manufacturer. These can be in the shape of a circle, an ellipse or a trapezium. The concern of measuring to a reflector that the laser beam is "striking" perpendicular to is that the added reflection of the beam has expanded past the diameter of the reflector. If the reflector is not perpendicular, then as can be seen in Figure 7 (Case with a divergence of the beam), the distance read can be inaccurate.

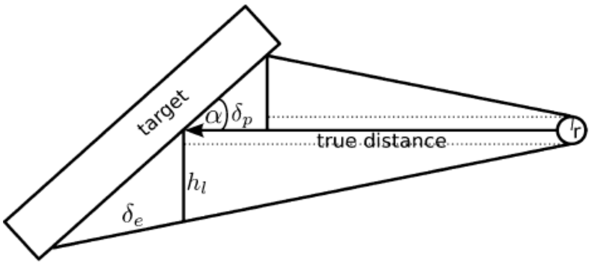


Figure 7. Case with a divergence of the beam (Kowalczyk & Rapinski, 2014).

As a result of this, all target faces measured in the experiment will be aimed as close to perpendicular, to ensure a flat surface, minimizing the error source shown above. ‘The size of the error caused by beam divergence depends on the incidence angle and on the shape of the target. Surveyors should avoid large incidence angles, and they should measure to a surface as perpendicular as possible.’ (Kowalczyk & Rapinski, 2014).

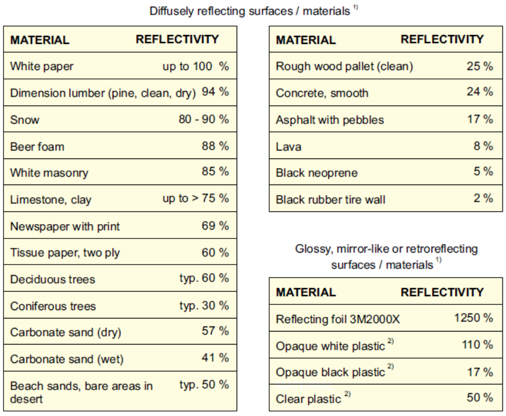
TRIMBLE state the beam divergence for the S6 total station is 4 cm/100 m in horizontal and 8 cm/100 m in the vertical axis (Trimble Navigation Limited, 2013). This relates to approximately 01’ 23” horizontally and 02’46” vertically, creating an elliptical field of potential reflectance of approximately 0.3 x 0.6m at the full extent of the 750m range. Referring that any object capable of returning a signal in the area of the ellipse, can problematically affect the quality of that reading, assuming the signal returned is strong enough.

]

2.6 Background Objects

Different objects will reflect light in a different way and the strength of the returned signal from an object is called the reflective coefficient. Results of Riegl’s (2002) tests of various surfaces/ materials, showing values for reflectivity returned can be seen in

Figure 8. Reflectivity of Various Surfaces/ Materials (RIEGL, 2002).



Diffusely reflecting surfaces / materials 1)

MATERIAL	REFLECTIVITY
White paper	up to 100 %
Dimension lumber (pine, clean, dry)	94 %
Snow	80 - 90 %
Beer foam	88 %
White masonry	85 %
Limestone, clay	up to > 75 %
Newspaper with print	69 %
Tissue paper, two ply	60 %
Deciduous trees	typ. 60 %
Coniferous trees	typ. 30 %
Carbonate sand (dry)	57 %
Carbonate sand (wet)	41 %
Beach sands, bare areas in desert	typ. 50 %

MATERIAL	REFLECTIVITY
Rough wood pallet (clean)	25 %
Concrete, smooth	24 %
Asphalt with pebbles	17 %
Lava	8 %
Black neoprene	5 %
Black rubber tire wall	2 %

Glossy, mirror-like or retroreflecting surfaces / materials 1)

MATERIAL	REFLECTIVITY
Reflecting foil 3M2000X	1250 %
Opaque white plastic 2)	110 %
Opaque black plastic 2)	17 %
Clear plastic 2)	50 %

Figure 8. Reflectivity of Various Surfaces/ Materials (RIEGL, 2002).

The objects chosen were thought to be common real world surroundings with reflective qualities, and potentially able to return signals from the total station. There were two categories and 3 example from each were chosen.

- Background/Reflective
  - Water
  - Tail Light Assembly
  - Reflective Road Sign
- Obstruction
  - Glass
  - Expanded Mesh
  - Vegetation

The interfering objects above have been chosen because reasons stated below.

- Background/Reflective
  - Water
    - Previous field complications with water as a background, this has been when difficulties in recording measurement for topographic survey with a lake/ canal/ river in the background or foreground.
    - This has also shown problems with the tracking of one target with object in the foreground of the target. Previous field work has identified that “target lock” can actually be achieved and measurements can be recorded with the instrument aiming at the reflection of the target on the water surface.
    - Commonly found object in surveying projects.

- Tail Light Assembly
  - “Measurements to strongly reflecting targets such as traffic lights in Prism mode without a prism should be avoided. The measured distances may be wrong or inaccurate” (Leica recommendations of correct procedures, 2008.)
  - The Tail Light Assembly chosen is comprised of similar component as traffic lights.
  - Previous experiences in field have also found interference in tracking of target when vehicle taillights travel through field of view.
  - Commonly found object in surveying projects.

- Reflective Road Sign
  - Previous experience in the field with interference in tracking of target with retro-reflective signs.
  - The colour red chosen from results of TJM Kennie, 1983 and Lang, 1980. “In 1980, Lang’s experiment found similar results. The results were that the four colours of AMERACE reflector tested, the red reflector returned signal 10% better than the orange. This effect was consistent with the other colours (Crystal, green) continuing to decrease by 10% respectively.” (TJM Kennie, (1983))
  - Litchi, Gordon and Tipdecho investigating Error Models and Propagation in Directly Georeferenced Terrestrial Laser Scanner Networks also found that when scanning a 10-mm diameter retro-reflective target, errors in distance occurred as large as 135mm; this was with the Cyra Cyrax 2500 Laser scanner (Litchi D, Gordon S and Tipdecho T, 2005).
  - Commonly found object in surveying projects.

- Obstruction
  “When a distance measurement is triggered, the EDM measures to the object which is in the beam path at that moment. If for example people, cars, animals, or swaying branches cross the laser beam while a measurement is being taken, a fraction of the laser beam is reflected from these objects and may lead to incorrect distance values.” (Leica recommendations of correct procedures, 2008).

    - Glass
        - Commonly found object in urban surveys.
    - Expanded Mesh
        - Previous experience with metal objects providing an interference with accuracy when an obstruction has been the major influencing factor when choosing this object.
        - Pesci and Teza 2008, found that through the testing of three types of metals, (iron, copper and aluminium plates) these proved problematic when measuring with laser scanning techniques.
        - Commonly found object in urban surveys.
    - Vegetation
        - Commonly found object in surveying projects.

The objects will be tested at different distances from the instrument for each station. For this project, we consider three different distances for position of the interfering object. These are:

- 10 m from the instrument;
- Half way in between the instrument and prism; and
- 10m from the prism

The stations are set at following distances:

- 25m
- 50m
- 100m
- 200m
- 400m
- 750m

2.7 Instruments Used

The instruments used for the experimental part of this thesis are the TRIMBLE S6 DR300+ and 5600 DR300+ total stations. These can be seen in the following figures, Figure 9. **TRIMBLE S6** (Trimble Navigation Limited, (2015)).Figure 10. **TRIMBLE 5600** (Inland Gps, N.D). Respectively.

2.7.1 Trimble S6

Released in May 2005, The Trimble S6 was the upgrade from the previous 3600 and 5600 models, claiming to have improved performance in accuracy, precision and usability. Trimble boasts that there are numerous improvements including MultiTrack™ technology combines passive tracking with active Target ID, MagDrive™ servo technology for incredibly fast, smooth performance, SurePoint™ accuracy assurance automatically corrects instrument pointing, as well as 100% cable-free instrument and Robotic rover (Trimble Navigation Limited, 2013). The Trimble S6 instrument used has the Trimble DR300+ technology integrated.

Figure 9. TRIMBLE S6 (Trimble Navigation Limited, (2015)).

The specifications for the TRIMBLE S6 DR300+ are as follows,

Table 1. Trimble S6 Instrument Specifications.

DISTANCE MEASUREMENT

Accuracy (RMSE)	
Prism mode	
Standard	**2 mm + 2 ppm** (0.0065 ft. + 2 ppm)
Standard deviation according to ISO17123-4	1 mm + 2 ppm (0.003 ft. + 2 ppm)
Tracking	4 mm + 2 ppm (0.013 ft. + 2 ppm)
DR mode	
Standard	**2 mm + 2 ppm** (0.0065 ft. + 2 ppm)
Tracking	4 mm + 2 ppm (0.013 ft. + 2 ppm)
EDM SPECIFICATIONS	
Light source	Pulsed laser diode 905 nm, Laser class 1
Laser pointer coaxial (standard	Laser class 2
Beam divergence	
Horizontal	4 cm/100 m (0.13 ft. /328 ft.)
Vertical	8 cm/100 m (0.26 ft. /328 ft.)
Atmospheric correction	–130 ppm to 160 ppm continuously

(Trimble Navigation Limited, 2013)

2.1.2 Trimble 5600

The Trimble 5600 series was introduced in 2001 and in 2002 came the introduction of DR Standard and DR300+. The system included all the features that are typical for Geodimeter, such as servo-assisted drive (optional), numeric or alpha-numeric control units (keyboards), track light, tracker (optional), radio side cover (optional) and RS-232C communication. (Trimble Navigation Limited, 2004). The Trimble 5600 instrument used has the Trimble DR300+ technology integrated.

Figure 10. TRIMBLE 5600 (Inland Gps, N.D).

The specifications for the TRIMBLE 5600 DR300+ are as follows.

DISTANCE MEASUREMENT

Accuracy (standard deviation)	
Prism	
Standard measurement	.± (3 mm + 3 ppm) ± (0.01 ft. + 3 ppm)
Fast Standard	.± (8 mm + 3 ppm) ± (0.025 ft. + 3 ppm)
Tracking	.± (10 mm + 3 ppm) ± (0.032 ft. + 3 ppm)
Arithmetic mean value (D-bar)	.± (3 mm + 3 ppm) ± (0.01 ft. + 3 ppm)
DIRECT-REFLEX MODE	5–300 m (16.4 ft.–984 ft.)
Standard measurement.	.± (3 mm + 3 ppm) ± (0.01 ft. + 3 ppm)
Fast Standard	.± (8 mm + 3 ppm) ± (0.025 ft. + 3 ppm)
Tracking	.± (10 mm + 3 ppm) ± (0.032 ft. + 3 ppm)
Arithmetic mean value (D-bar)	.± (3 mm + 3 ppm) ± (0.01 ft. + 3 ppm)
>300 m (984 ft.	± (5mm + 3 ppm) ± (0.016 ft. + 3 ppm)
Light source	Pulsed laser diode 870 nm
Laser pointer eccentric (optional)	.Laser class 2
BEAM DIVERGENCE	
Horizontal	0.4 mrad (4 cm/100 m) (0.13 ft. /328 ft.)
Vertical	0.8 mrad (8 cm/100 m) (0.26 ft. /328 ft.)
Laser class 1	

Figure 11 Trimble 5600 Instrument Specifications (Trimble Navigation Limited, 2004)

2.8 Prisms Used

The types of prisms used are the TRIMBLE SUPER Prism and the TRIMBLE MT1000 Multitrack 360 Degree Target

The TRIMBLE SUPER PRISM consists of one prism with a high tech mirror surface. It is a zero offset prism with a diameter of 63.5mm. See below in Figure 12. TRIMBLE Super Prism

Figure 12. TRIMBLE Super Prism

The Trimble MT1000 multitrack 360 prism has a total of 8 prisms. See Figure 13 TRIMBLE MT1000 360 Multitrack Prism Active Tracking Diodes

- Prism Constant: 10mm
- Prism Accuracy: 5”
- Prism Size: 20mm
- Tracker Range: 800m

Figure 13 TRIMBLE MT1000 360 Multitrack Prism

Chapter 3 Methodology

3.1 Calibration

To ensure that the measurements recorded are accurate and to eliminate variables other than the one being tested, it is essential to confirm that the instruments being used are functioning correctly and in proper working order. To achieve this, the instruments were calibrated beforehand.

Cadastral surveyors, under Section 20 of the *Survey and Mapping Infrastructure Regulation 2014* are required to certify that the equipment used meets classification. That is that the instruments are;

- Standardised;
- Capable of achieving the required accuracy.

A set of baselines meeting regulation 13 certification under the National Measurement Act 1960, have been established and maintained by the Department Natural Resources and Mines. These services are for the use of surveyors to enable them to endorse the traceability of the EDM instruments used to national standards.

‘Surveyors can achieve traceability of length measurement for EDME by comparison with one of the baselines. Such comparisons should be carried out in accordance with the EDME Comparison Procedure, and include the prisms used with the EDME for distance measurement.’ (Department of Natural Resources and Mines, 2015).

The calibration process was taken place over the Caboolture range and calibration reports can be seen in Appendices D – Calibration Reports.

3.2 Control of Variables

Experiments were undertaken over 4 weekends, with the atmospheric conditions for temperature and pressure inserted for each experimental undertaking. The temperature readings were recorded in the field and the pressure from the Beerburrum weather station. Each section of the experiments were completed as close to each other as possible to keep atmospheric conditions the same, in aims to reduce any differences caused by change in atmospheric effects.

For aiming of the instrument, the total station will be manually aimed at the target; the first set of measurements without interference will be taken to determine a true distance. Then the interfering object will be added in keeping the total station at the same horizontal and vertical angles. ATR will not be used as Weyman Jones (2010) has expressed errors in aiming with obstruction and interference with ATR conclusions being

- The total station will still read to a half covered round prism; however it will force a deflected reading of approximately half a prism width;
- The closer the obstruction is to the total station the more severe the effect the obstruction will have on the ATR reading in all cases.

M Erikson (2014) states “Trusting the precision of the TS alone while not paying attention to the prisms – the centring, the angling and the quality – will have an effect on the accuracy.”

3.3 Experiments

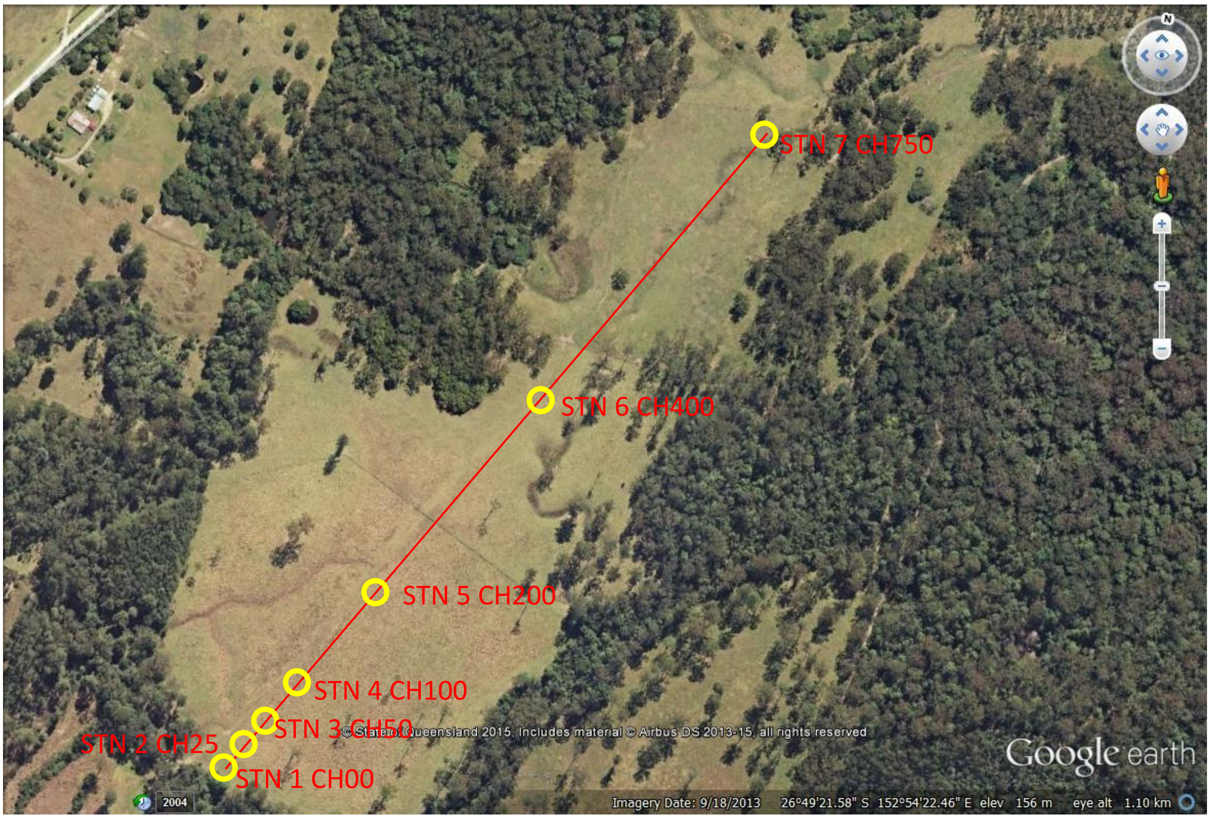
For each of the experiments,

- Both TRIMBLE SUPER Prism and the TRIMBLE MT1000 Multitrack 360 Degree Target were used and some cases Direct Reflex- where applicable
- 10 measurements were recorded to achieve the average for each distance

This procedure will be replicated by both total station instruments to confirm that errors are not related to the instrument.

A range was created in a flat open space, with targets set at varying distances to test if there was a particular distance/ interval that interference might have an effect. Two ranges were created – range 1 and range 2. These can be seen below in Figure 14. Range 1 (Used for Experiment 1 and 3).

Figure 14. Range 1 (Used for Experiment 1 and 3).



The range was set up as follows at approximate chainages

Table 2. Stations and Chainages.

STN	**1**	**2**	**3**	**4**	**5**	**6**	**7**
CH	0	25	50	100	200	400	750
ΔDIST		25	25	50	100	200	350

For the ranges, targets were set up without causing obstruction, with the total station placed on station 1.

Range two was set on a hill with a dam below. 4 stations were used at chainages 0, 25, 50 and 100m. The range can be seen below in Figure 15. Range 2 (Used for Experiment 2).

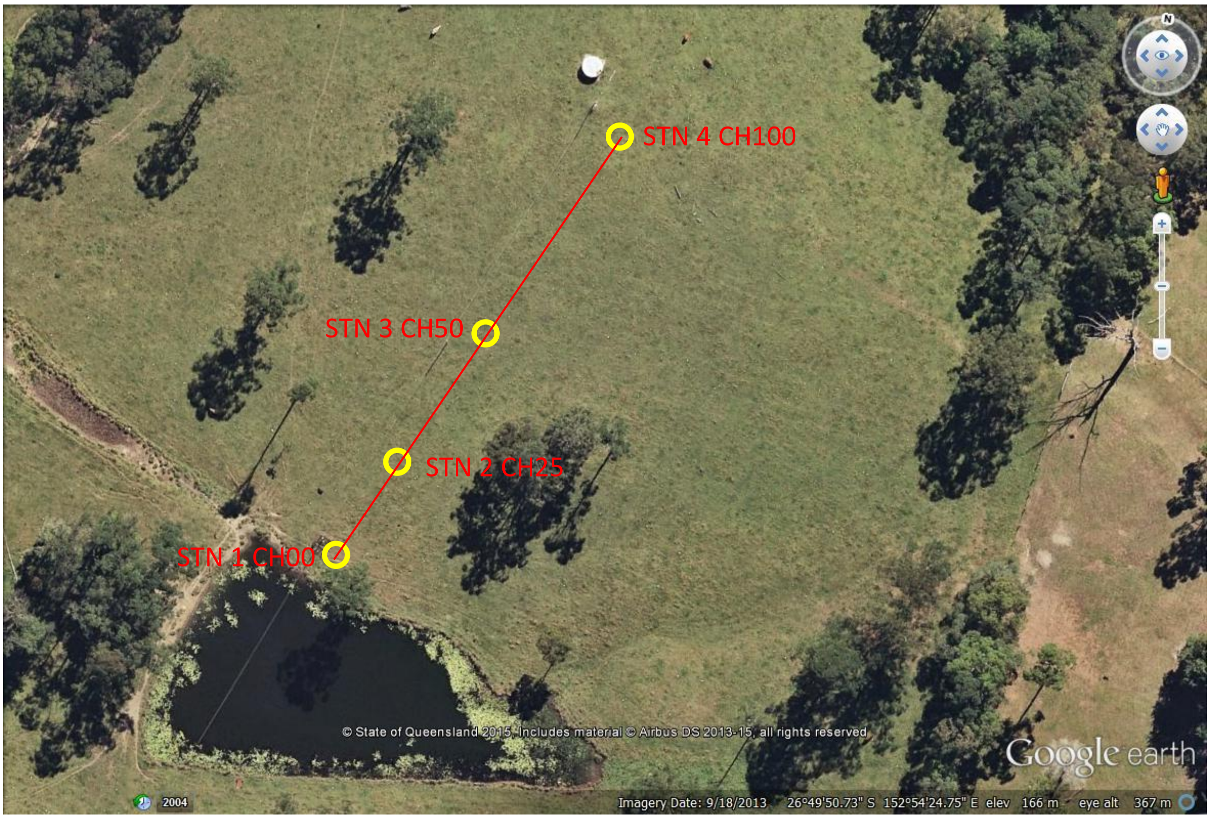


Figure 15. Range 2 (Used for Experiment 2).

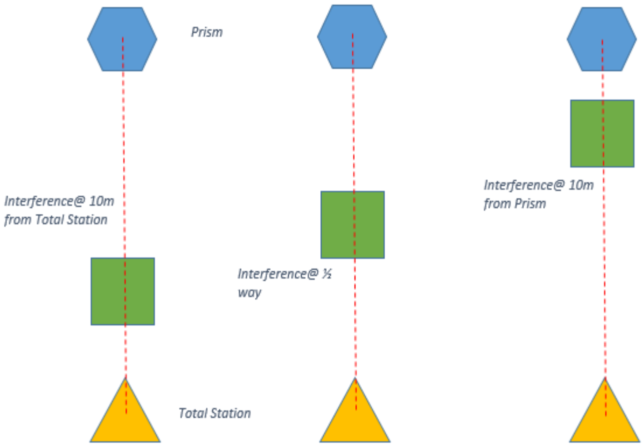
Before any field experiments could begin, a workplace risk assessment was completed to identify and control any potential hazards. This can be seen in Appendices C – Risk Assessment. Table 15. Risk Assessment Matrix Tool. Table 16. Consequence Assessment Tool.

3.3.1 Experiment 1 External Retro Reflective Interference of Intended Prism/360 Prism Measurement

For this experiment range 1 was used. A target was set up on each station and measured individually without interference to establish a true distance measurement. Once this had been confirmed, the interference was added. These were measured at 10m from the instrument, ½ ways between the target and instrument, 10m from the target and 10m behind the target. This procedure was completed with each station.

An example of interference object can be seen below in Figure 16. Interfering Object Placement for Each Station

Figure 16. Interfering Object Placement for Each Station.



The interferences used were a retro-reflective road sign and Tail Light Assembly. These can be seen below in

Figure 17. Sign set-up Experiment 1.

Figure 18. Sign set-up Experiment 1.

Figure 17. Sign set-up Experiment 1.

Figure 18. Sign set-up Experiment 1.

3.3.2 Experiment 2 External Background (Water) Interference of Intended Prism/360 Prism Measurement

For this experiment, range 2 was used, set- up on a hill with a dam located at the bottom.

Station 1 was located closest to the dam, and the total station was set there. Stations 2, 3 and 4 were then placed and measured up the hill at 25m 50m and 100m respectively. Once a base line had been established the prism was placed on station 1 and the total station was moved to 2, 3 and 4 to measure the distances again with the water in the background. Photos of the station set ups can be seen below in Figure 19. Range Set up Experiment 2 (at Station 3).Figure 20. Experiment 2. Figure 21. Super Prism placement Experiment 2 Figure 22. MT1000 360 Multitrack Prism Placement Experiment 2.

Figure 19. Range Set up Experiment 2 (at Station 3).

Figure 20. Experiment 2.

Figure 21. Super Prism placement Experiment 2

Figure 22. MT1000 360 Multitrack Prism Placement Experiment 2.

3.3.3 Experiment 3 External Obstruction Interference of Intended Prism/360 Prism Measurement

This experiment used range 1, same as experiment 1. A target was set up on each station and measured individually without interference to establish a true distance measurement. Once this had been confirmed, the interference was added. These were measured at 10m from the instrument, ½ ways between the target and instrument, 10m from the target and 10m behind the target. This procedure was completed with each station. The interferences used were measuring through vegetation, steel mesh and glass. These can be seen below in

Figure 23. Glass Obstruction set-up

Figure 24. Glass Obstruction set-up

Figure 25 Expanded Mesh Obstruction set-up

Figure 26 Expanded Mesh Obstruction set-up

Figure 27. Vegetation Obstruction Experiment 3.

Figure 23. Glass Obstruction set-up

Figure 24. Glass Obstruction set-up

Figure 25 Expanded Mesh Obstruction set-up

Figure 26 Expanded Mesh Obstruction set-up

Figure 27. Vegetation Obstruction Experiment 3.

Chapter 4 Results and Discussion

For Tabulated results refer to Appendices B -Tabulated results of field experiments

4.1 Experiment 1 External Retro Reflective Interference of Intended Prism/360 Prism Measurement

4.1.1 Trimble S6

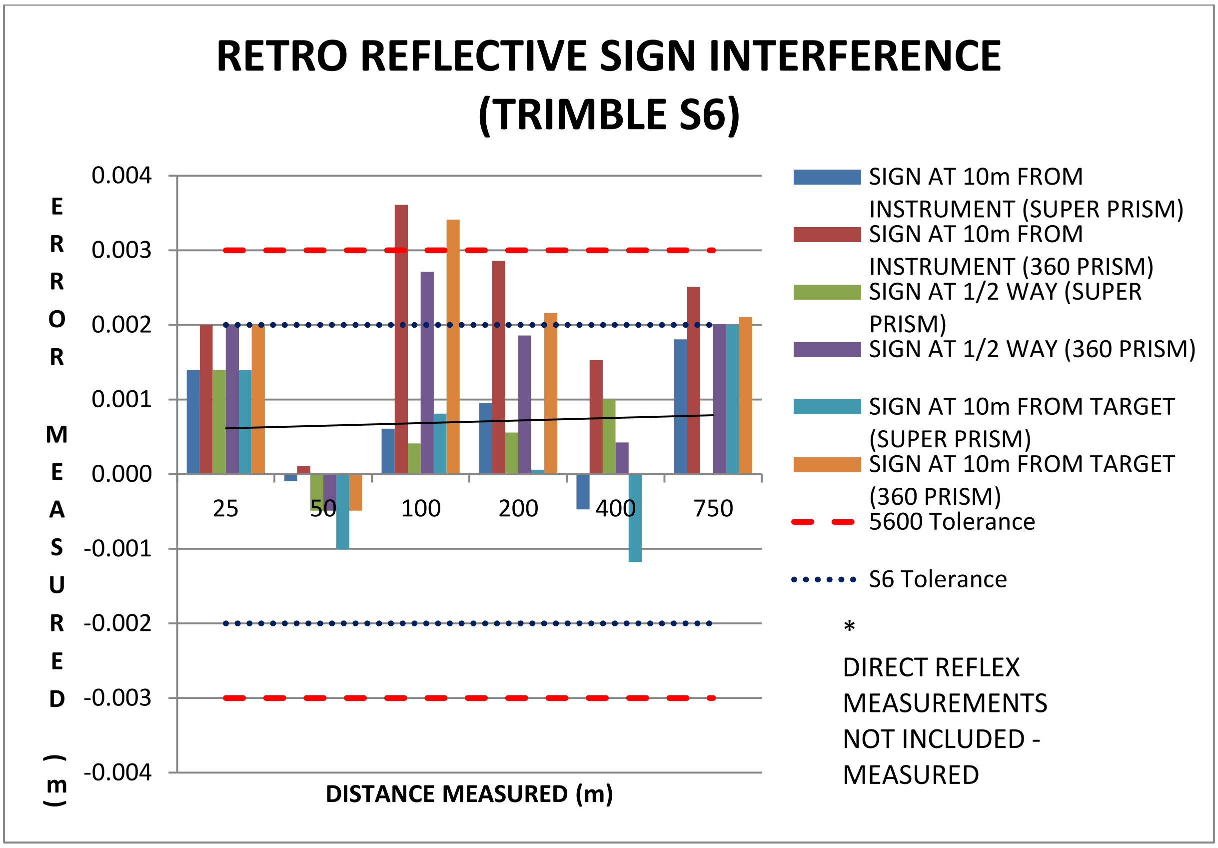
4.1.1.1 Sign

The results for the interference caused by the sign with a retro-reflective coating showed that the majority of the measurements were within tolerance of the instruments manufacturer. There were 5 measurements that fell outside of the ± 2mm tolerance. These were all while measuring to the 360 prism, with sign at 10m from the instrument at 100, 200 and 750m, sign at ½ way 100m and sign at 10m from target at 100m. These errors were 4, 3, 3, 3 and 3mm respectively. The worst results for the super prism were recorded at the 750m station as consistent with the trend of the data but these were still within the 2mm instrument tolerances.

By examining the trend line for this data, it can be seen that a slow decrease in accuracy is occurring as the distance increases. However it appears that 100m is a problematic distance for measuring the 360 prism with a retro reflective sign at all positions tested. The 200m results for the 360 degree prism also show an area of inconsistency. This is seen especially with the precision between the super prism and the 360 prism. All results are reasonably precise, with a range of 1mm in the averages for all stations and positions of the sign tested, except for 100m and 200m. At these distances the 360 prism measured consistently 2-3mm further from the true result compared to the super prism.

The direct reflex measurements were not included in the results as all were gross errors measuring to the sign for each station and position.

Figure 28. External Retro Reflective Interference (Sign) S6.

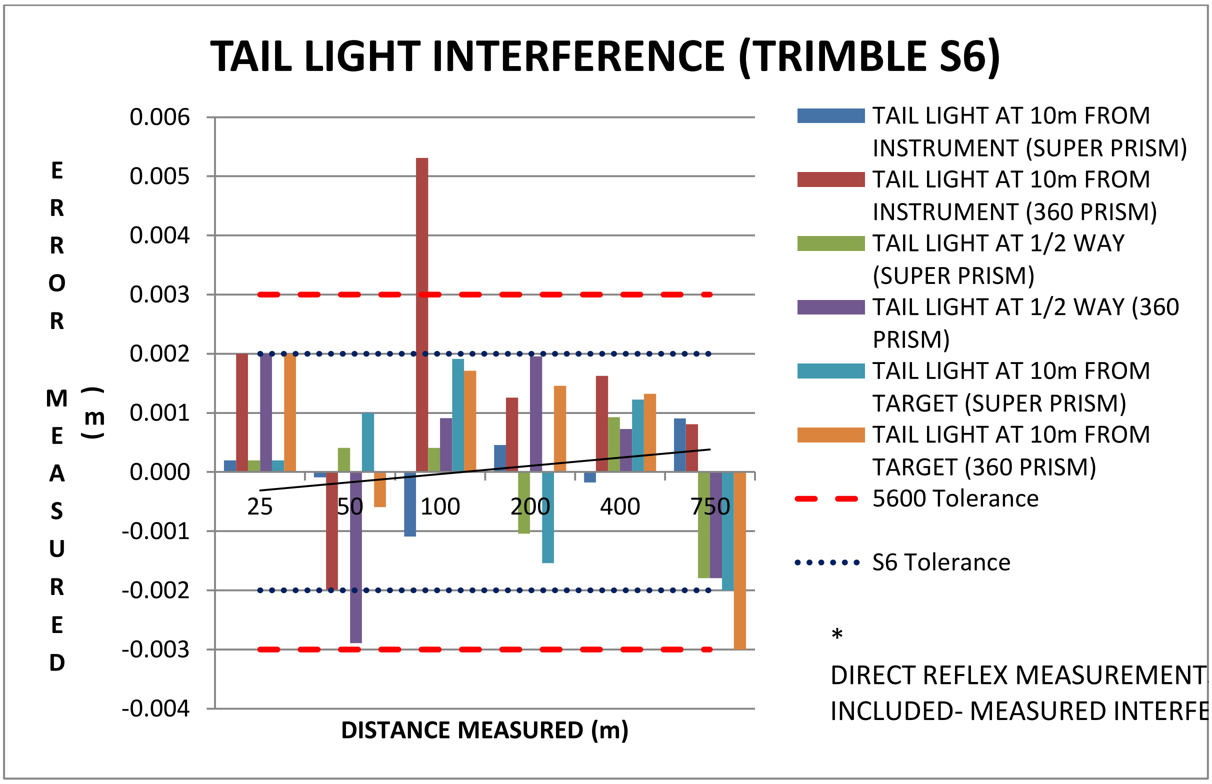


4.1.1.2 Tail Light Assembly

The 3 measurements outside of tolerance with the Tail Light Assembly being used as potential interference were those measuring the 360 prism. The results outside of tolerance were not of a consistent station or Tail lights at a particular distance, with the errors being 360 prism measured at 50m with tail lights at ½ way, 100m with sign at 10m from instrument and 750m with tail lights at 10m from target. These errors were 3mm, 5mm and 3mm respectively. The most inaccurate measurements recorded for the super prism were those at 100m, 200m and 750m all with the tail lights at 10m from the target. These still fell within tolerance at 2mm from the true distance. For the 360 prism the tail lights at 10m from the target at 100m measured worst, being 5mm in error.

The trend line of the data shows a very slight increase in error as distance increases. The accuracy of the super prism appeared to be much better than that of the 360 prism at ranges of 25m, 50m, 100m and 200m. The difference between the 2 prism at stations 400 and 750 were less than 1mm. The direct reflex measurements were not included in the results as all were gross errors measuring to the Tail Light Assembly

Figure 29. External Retro Reflective Interference (Tail Light Assembly) S6.



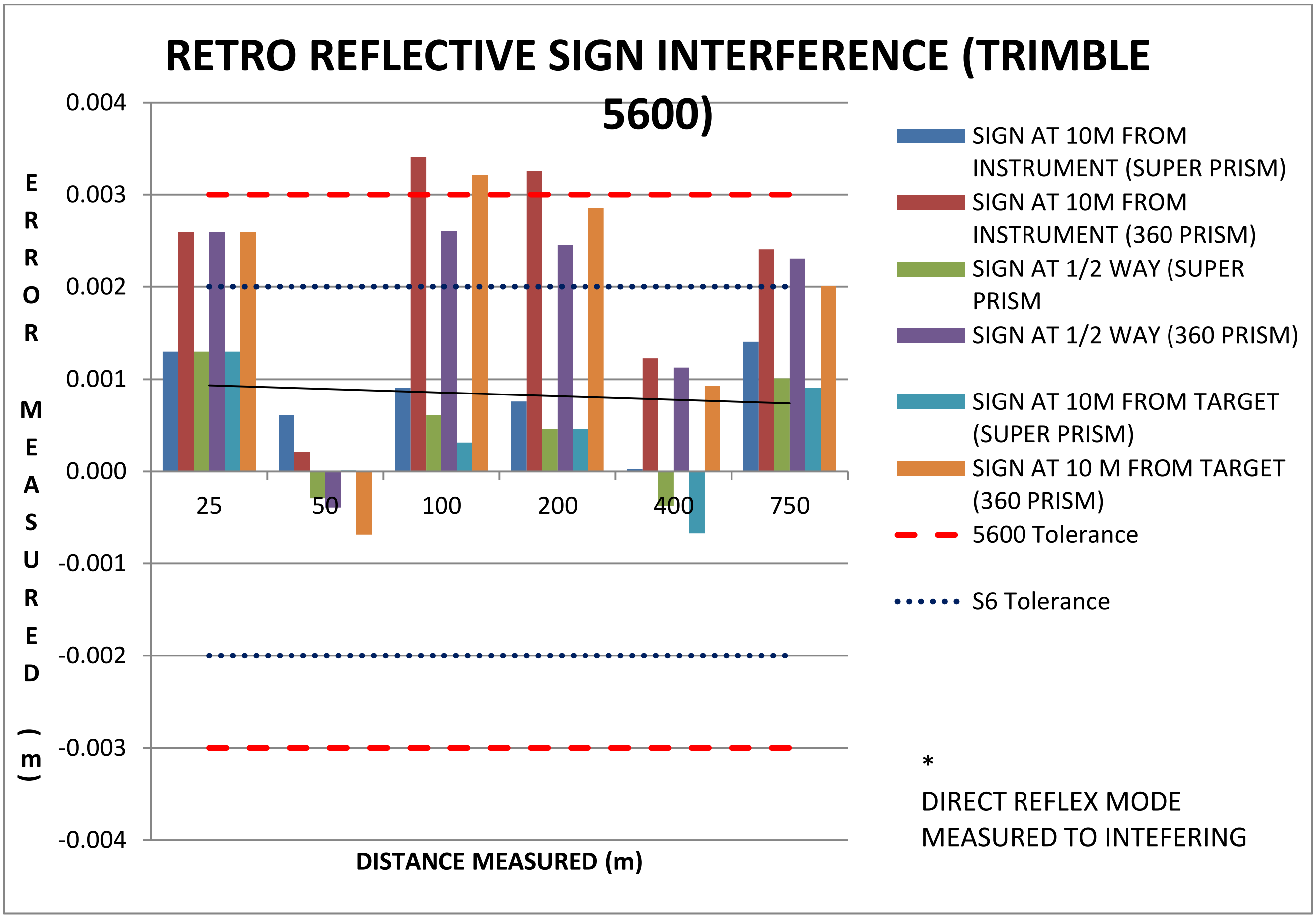
4.1.2Trimble 5600

4.1.2.1 Sign

Measurements for the 5600, only 3 of the averages fell outside of tolerance but with rounding to the nearest mm, are within the ±3mm stated by Trimble. If you compare the results to the tolerance of the S6 instrument though, a majority of the 360 prism measurements fall outside of the ±2mm.

There appears to be minimal fluctuation in relation to error occurred with distance. Like the S6 instrument, results measuring to the 360 differed most when compared to the true distance. The results of the super prism and 360 prism seem to be reasonably precise with changing locations of the signs position. And the 360 prism always measured most inaccurately compared to the super prism. Also like the results obtained by the S6 distances of 100 and 200m appear to be problematic for the 360 prism with the sign at all locations tested. The direct reflex measurements were not included in the results as all were gross errors measuring to the sign.

Figure 30. External Retro Reflective Interference (Sign) 5600.



4.1.2.2 Tail Light Assembly

Only one out of tolerance measurement was recorded for the 5600 when measuring with the Tail Light Assembly providing interference. This was measuring the 360 prism at 100 with the Tail Light Assembly at 10m from the instrument. This combination of station and Tail Light Assembly position also measured badly with the S6 instrument.

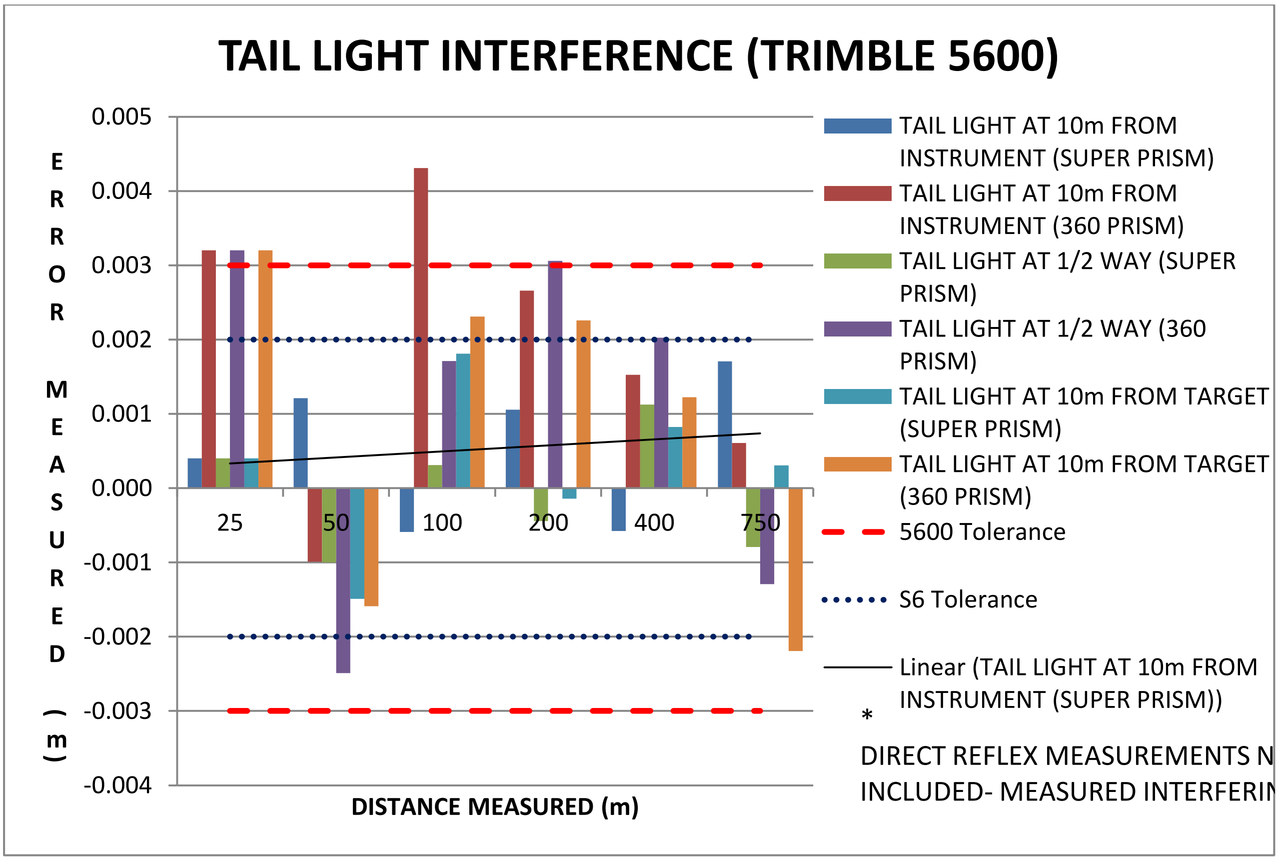
There are 2 trends to the data recorded for the testing of this instrument.

- The measurements for the super prism show to be reasonably accurate for all measurements with a slight increase in inaccuracy as distance increases.
- The trend for the accuracy of the 360 prism is that it improves as distance increases.

The precision of the data recorded for change in tail lights position also varies more as the distance measured increases. This is for both the super prism and the 360 prism.

The direct reflex measurements were not included in the results as all were gross errors measuring to the Tail Light Assembly.

Figure 31. External Retro Reflective Interference (Tail Light Assembly) 5600.



4.1.3 Conclusion

4.1.3.1 Sign

For both instruments it is easily identified that the super prism measured most accurately for the true distance compared to the results obtained for the 360 prism. All of the measurements that recorded outside of the manufactures tolerances were for the 360 prism. The 360 prism measured consistently erroneous for the stations 100m and 200m for all position of the sign. Both had a consistent trend that errors increased as distance increased. The majority of the 5600 measurements proved to be more accurate than the newer S6 model.

4.1.3.2 Tail Light Assembly

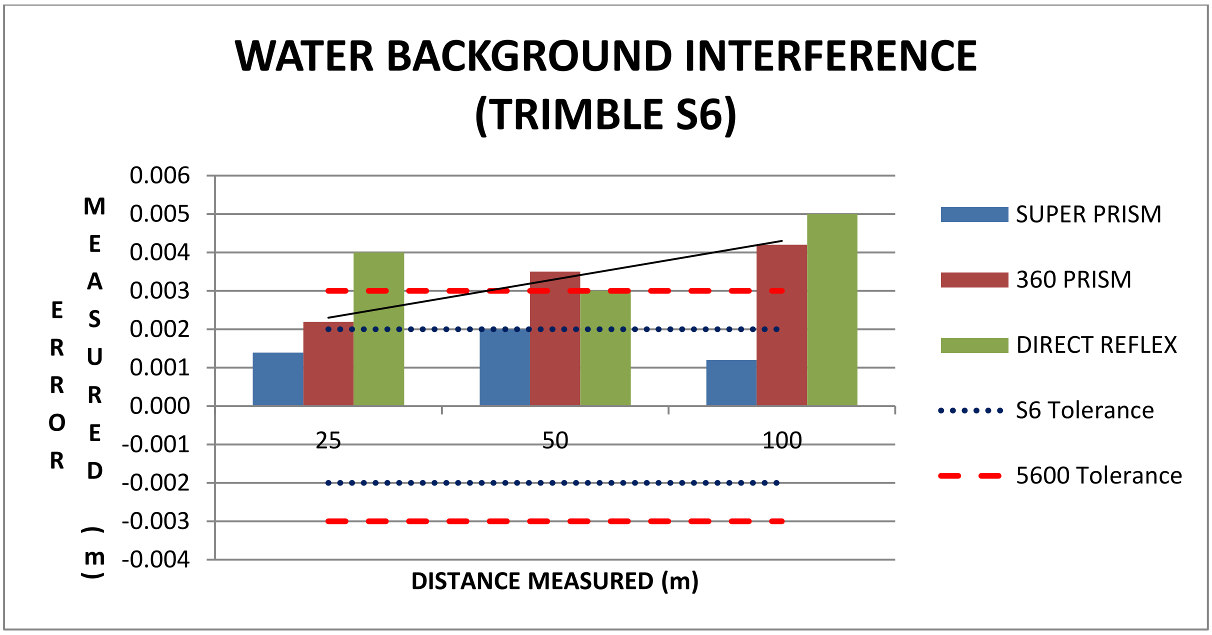
Both instruments showed similar measurements for the interference caused by the Tail Light Assembly. The older 5600 measured less accurately than the s6’s results. Both instruments measured to the super prism more accurately than to the 360 prism. And the results deteriorated the further the station was. There was no obvious station or positioning of the sign that proved to be a problem.

4.2 Experiment 2 External Background (Water) Interference of Intended Prism/360 Prism Measurement

4.2.1 Trimble S6

Super Prism measurements for the experiment were all with tolerance, leading to the notion that the effect of water behind a target being measured does not have an effect on the accuracy of that measurement. The measuring of the 360 prism were close to tolerance levels with an increase in recorded measurement as distances became further from the target being measured to. This was just outside, with 4mm increase being measured. When measuring Direct Reflex an increase in distance measurement was observed when distances changed. 25-50m 4mm and 50-100m 3mm, leading to a total range of 7mm. the trend line of the data recorded for the 360 and direct reflex measurements show that as the distance measured increase the accuracy decreases. However due to only having 3 distance measurements stating that errors would continually increase as station distances increased, would be unreliable. The most accurate and precise of the 3 types of measuring over all of the stations was the super prism. All of the measurements measured equal or greater than the true distance measured without interference.

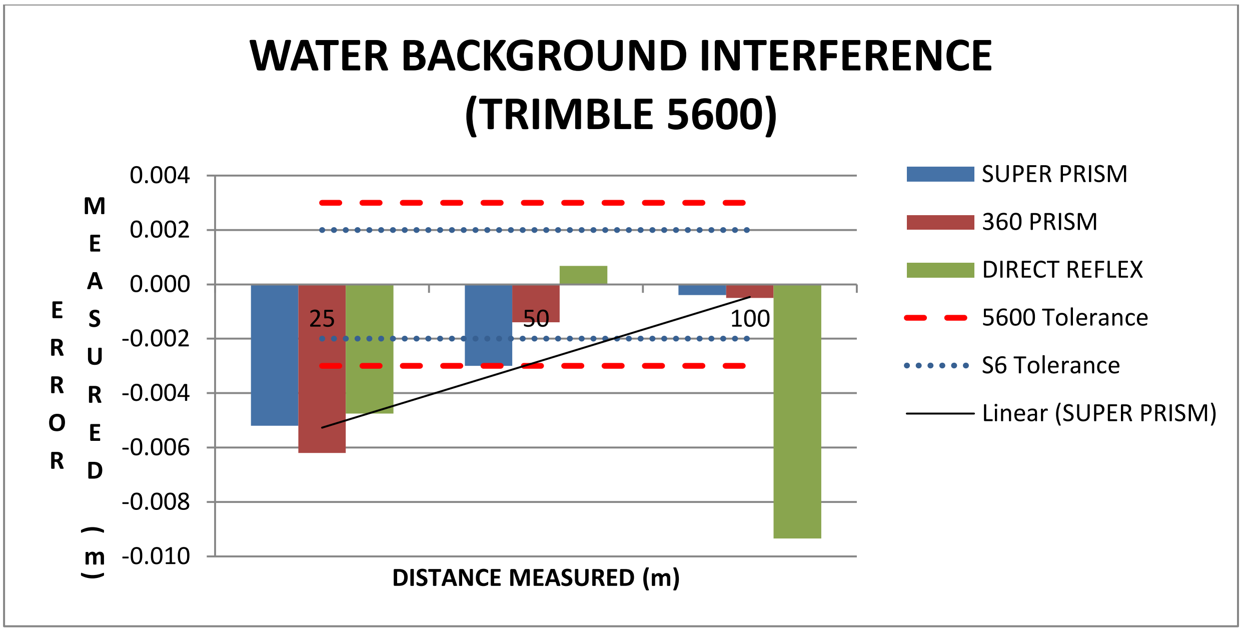
Figure 32. External Background Interference (Water) S6.



4.2.2 Trimble 5600

The distances recorded for this experiment appeared to have the opposite affect shown by the S6. The super prism measurements for 25m with water in the background were out of tolerance with 5mm, 50m showing 3mm and then continuing to improve at 100m with 1mm error. The results followed similar results for the 360 prism with 6mm for 25m, 1mm for 50m and the true distance measured at 100m. The direct reflex measured inconsistent with 4mm at 25m, 1mm at 50m and 9mm for the distance of 100m. The trend in data for super prism and the 360 show the further the measured distance the less effect that water has.

Figure 33. External Background Interference (Water) 5600.



4.2.3 Conclusion

The two total stations measured almost opposite of each other. The 5600 had greater errors when measuring short distances and water in the background, compared to the s6 which had shown to be less accurate over the longer distances.

4.3 Experiment 3 External Obstruction Interference of Intended Prism/360 Prism Measurement

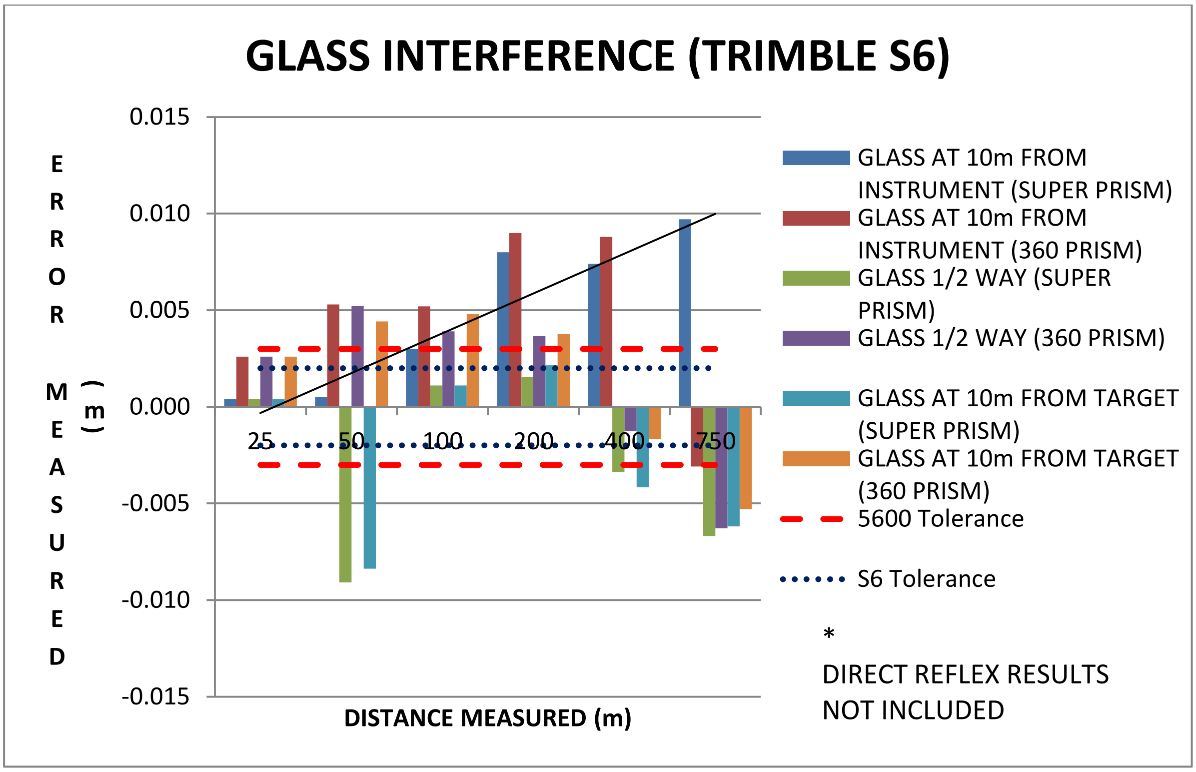
4.3.1 Trimble S6

4.3.1.1 Glass

The majority of the measurements recorded were out of manufacturer's tolerance with only 10 of 36 measurements recording in the ±2mm. a large number of the closer distances (25m - 200m) measured with the super prism fell within tolerances. Examining the effect of the glass it showed that the interference of the glass appeared to have less of an effect over the shorter distances and a decrease of accuracy occurred over the longer stations. Increases in error as the distance measured increases are evident in the case of glass at 10m from instrument. This is with the exception of measuring the 360 prism at 750m which still fell out of tolerance. There does not seem to have a reliable pattern for ½ way and 10m from target.

Measuring direct reflex almost all measurements recorded the glass. Only 2 measured to the intended target, with one of those being in tolerance. These were measuring 50 and 100m with the glass at 10m from the instrument. The results were 1mm and 8mm respectively. Measuring 200m with the glass at half way, 1 of the 10 recorded measured to the 200m target. This suggests that it may be possible to achieve DR measurements to all stations but is dependent on angle of the glass. The change of incidence angle was not investigated in the experiments. Each measurement was through the glass at as close to perpendicular as possible.

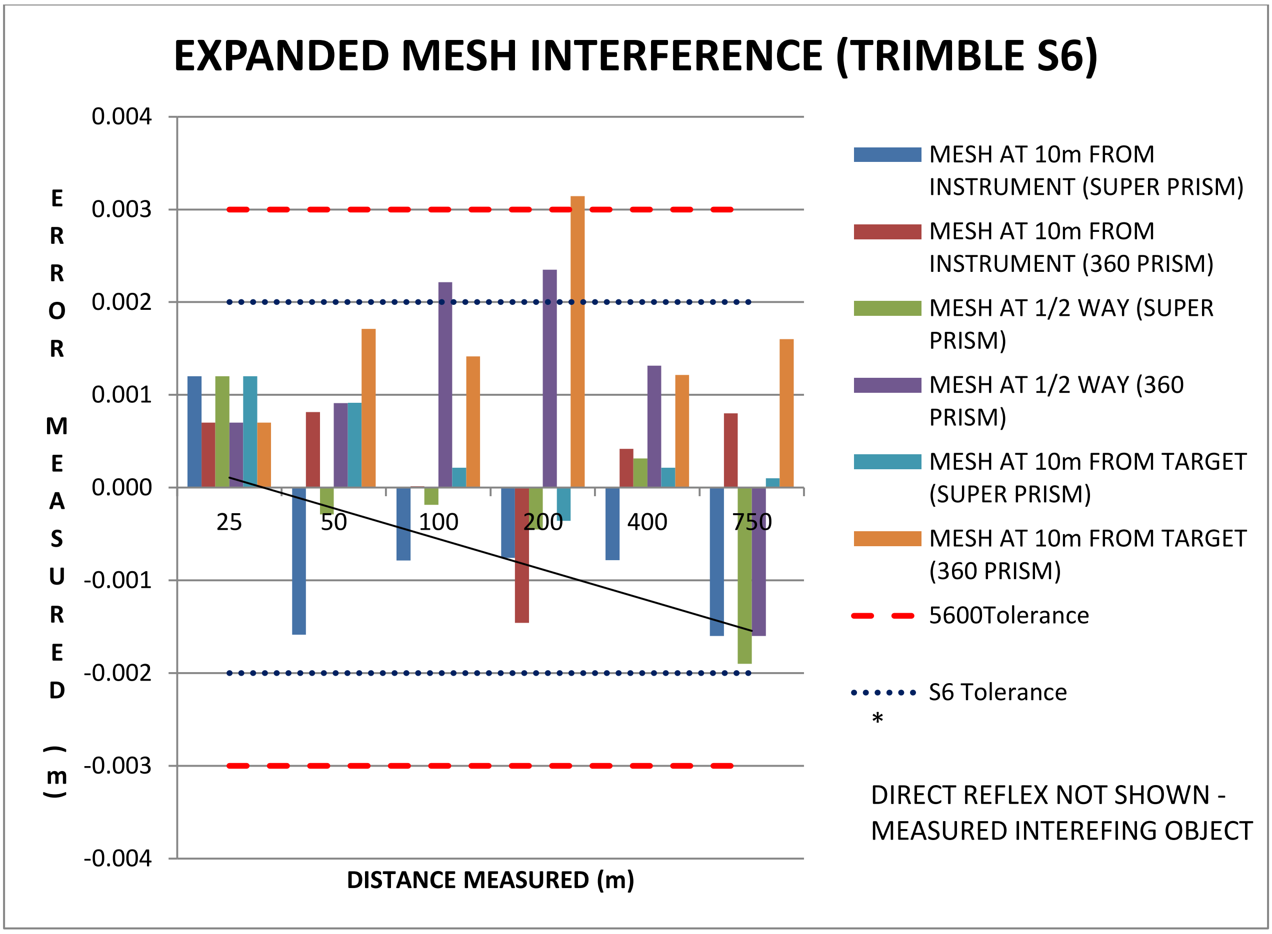
Figure 34. External Obstruction Interference (Glass) S6.



4.3.1.2 Mesh

Measuring with the expanded mesh showed all measurements within tolerance, with the exception of measuring the 360 prism at 200 with the mesh located at 10m from the target measuring 3mm excess. The data displays that minimal effect is caused by measuring through expanded mesh with the majority of measurements falling within ±1mm of the true distance. This shows measurements are reasonably accurate and precise. The trend line for the data does however show a slight increase in error as the distance increases. Direct reflex as suspected measured to the mesh on all occasions.

Figure 35. External Obstruction Interference (Mesh) S6.



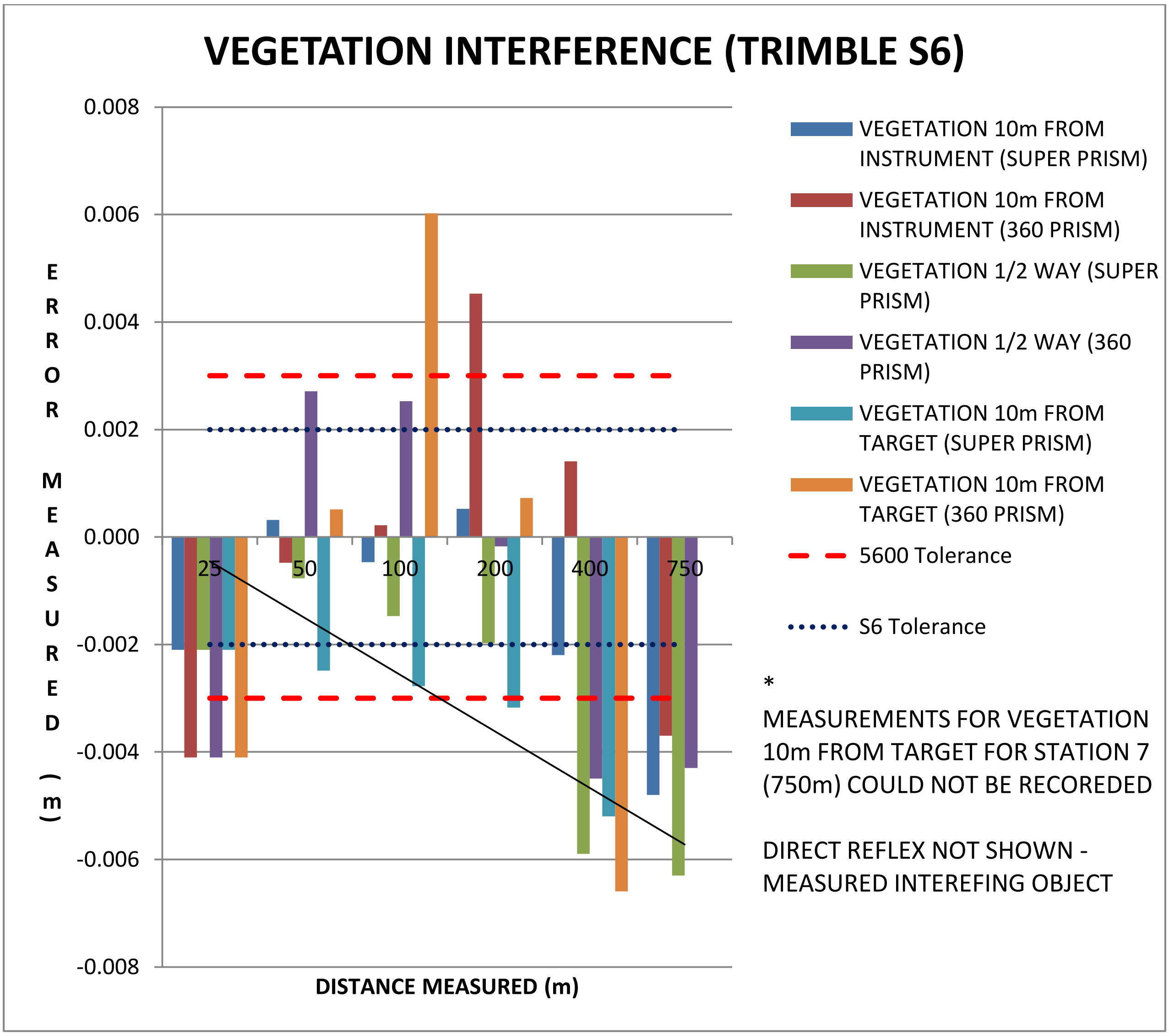
4.3.1.3 Vegetation

Almost ½ of the measurements fell outside of tolerance, when measuring through the obstruction of vegetation. Measurements for the super prism were significantly better than those of the 360 prism. There were however 2 reading at which no measurement was recorded. These were both for the 360 and super prism at 750m with the vegetation at 10m from the target. The worst measurements for accuracy recorded by the super prism was 6mm at 400m and 750m with the prism half way between the target and instrument. For the 360 prism errors of 6mm with the target at 100m and 400m.

Concurring with the mesh, measurements for the shorter station averaged closer to the true distance than the longer 400 and 750m stations. This effect however is much more pronounced than the mesh. The shorter stations however had a much larger range when comparing the effects of position of said vegetation. A possible explanation of this and the inability to record data for 10m from the target at 750m, is that at the shorter distances a much larger of the initial signal from the total station is able to hit the target, so an example being 90% of the beams signal is able to be returned compared to an exaggerated 10% for the furthest. It is also evident that the vegetation had a much larger obstruction when compared to that of the mesh.

Direct reflex measured to the vegetation obstruction on all stations.

Figure 36. External Obstruction Interference (Vegetation) S6.



4.3.2 Trimble 5600

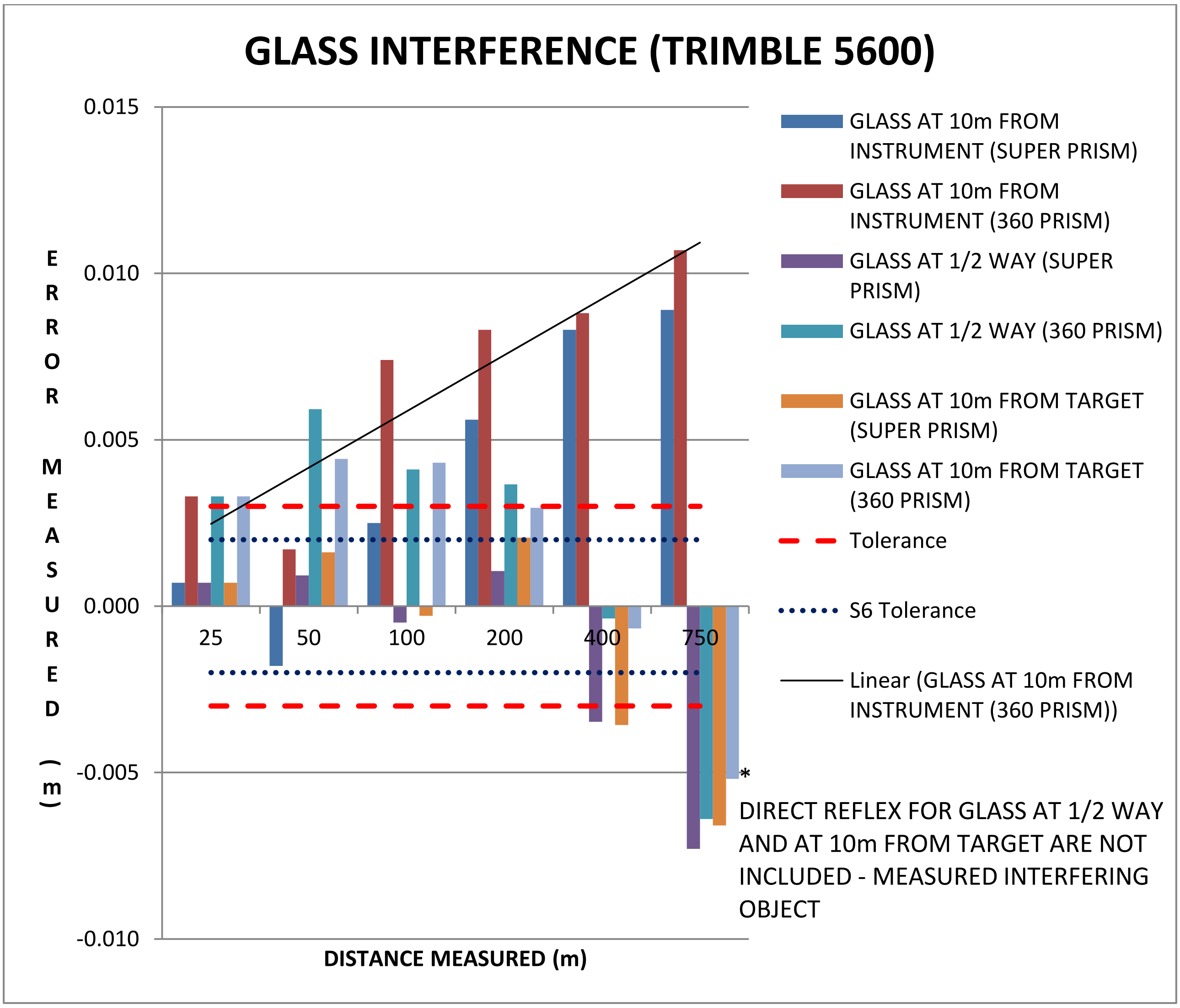
4.3.2.1 Glass

The 5600 compared much better than the s6 to perform within instrument tolerance, but equal for measuring a true distance. 17 of the 36 measurements fell outside tolerance with the worst recorded measurement being the 360 prism at 750m with the glass at 10m from instrument. A majority of the super prism measurements fell within the tolerances of the instruments ±3mm. the worst measurement recorded for the super prism was that at 750m with the glass at 10m from the target. This was also the same for the 360 prism, with values being 9 and 11mm respectively.

There is a clear trend showing that the error increases with distance for the glass at 10m from the instrument. These are all increasing in excess of distance. No clear trend occurs for the glass at ½ way and the glass at 10m from the target, but the data shows those stations further away have less measurement within tolerance. These however do not all measure the same but with a mix of out of tolerance excess and shortage.

Direct reflex measured the intended target with the glass at 10m from the instrument, with 25 and 50m measuring accurately, 100m measured 7mm error, and no measurement could be recorded at 200m. The remainder of the direct reflex measured the glass for ½ way and 10m from the target.

Figure 37. External Obstruction Interference (Glass) 5600.



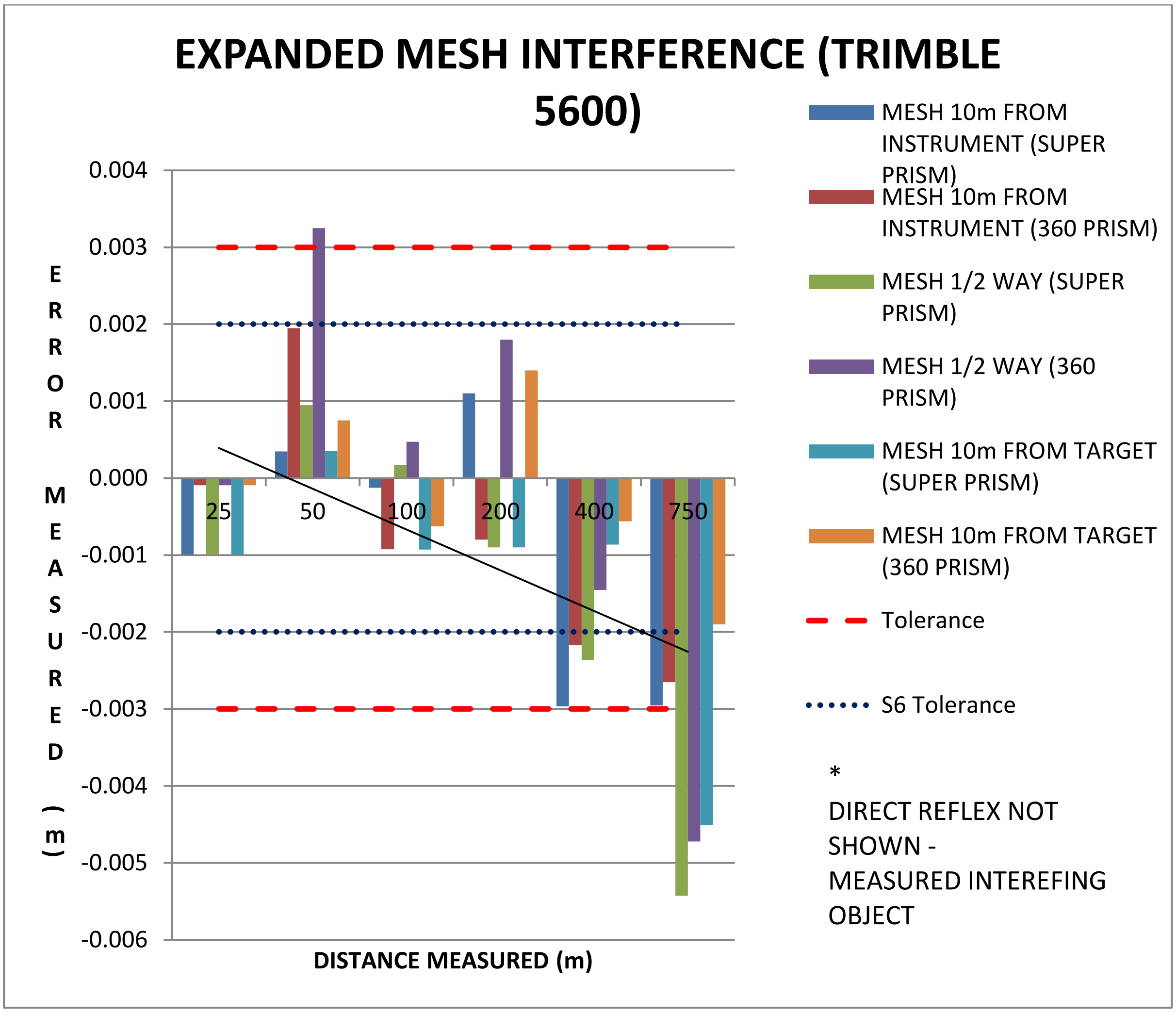
4.3.2.2 Mesh

This measured reasonably accurate for the first set of stations but at 400m and 750m the data seemed to drift much farther from the true distance than compared to the S6. This experiment showed 3 results outside the tolerance of 3mm. the maximum value was recorded at 5mm being the super prism and 360 prisms measured at 750m with the mesh ½ way between. The results show that little effect occurred at stations of 25m, 100m, and 200m with majority floating around ±1mm. 50m measured reasonably well with the super prism within the 1mm and the 360 measuring 2mm, 3mm and 1mm for 10m from instrument, ½ way and 10m from target respectively. The measurement for 400 and 750m all measured shortage, with a fluctuation of 3mm for 400 and 3mm range at 750m. The most accurate measurement for 750m was 10m from the target measuring the 360 prism at 2mm.

The data does not appear to replicate the other experiments with the super prism and 360 prism having similar results comparing accuracy. It does however follow the trend that the further stations, 400m and 750m resulted in the least accurate measurements. This is quite a clear trend easily seen from the graph. A small anomaly was a station of 50m only for the 360 prism. Apart from the further stations the change of position of the mesh does not seem to have a particularly large effect on accuracy either.

Direct reflex measured to the mesh at all stations and position of the mesh.

Figure 38. External Obstruction Interference (Mesh) 5600.



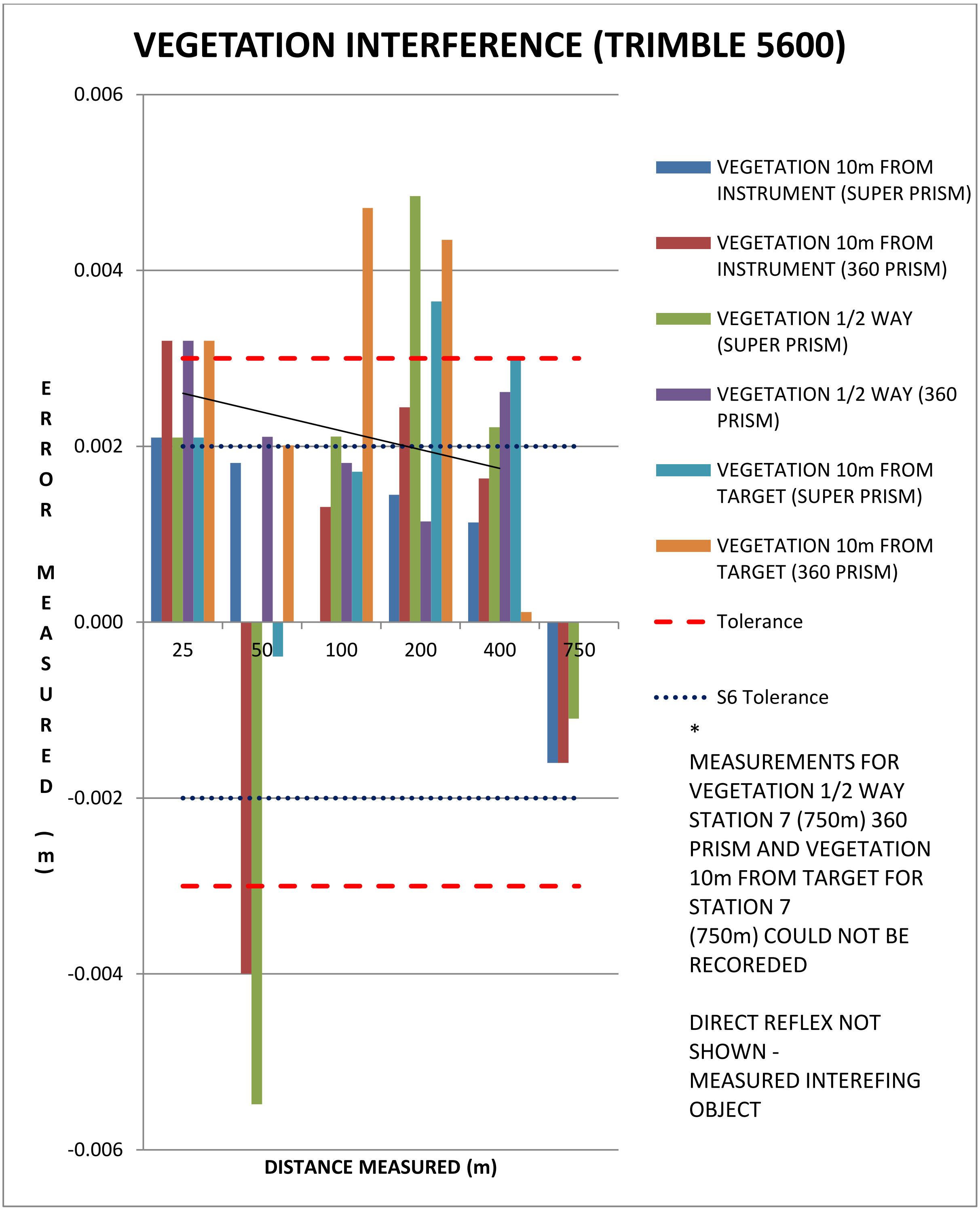
4.3.2.3 Vegetation

This experiment resulted reasonably well compared to the other obstruction tests. 6 out of all the measurements taken were out of tolerance with those being; the 360 prism at 50m with vegetation 10m from instrument, super prism at 50 with vegetation ½ way, 360 prism at 100m with vegetation 10m from target, 360m at 200m with vegetation ½ way and the super prism and 360 prism at 200m with vegetation at 10 m from target. The worst results of this experiment were the super prism at 50m and 200m vegetation ½ way measuring 5mm from the true distance, and the 360 prism at 100m with the vegetation at 10m from the instrument measuring 5mm from the true distance. The remainder of the measurements appear to measure excess but still within tolerance, except the 750m station which measured shortage. With the exceptions of 50m and 200m stations, the other measurements fell within a ± 1mm for the experiments tested, showing that while not the most accurate, position of the vegetation or the target measured to has reasonably high precision between results. Measurements for 750m with the vegetation at 10m from the target could not be obtained. Most like due to weak return signal of the EDM.

The trend line shows an increase in accuracy as the distance increase. This is only very slight however.

Measurements for the direct reflex measured to the vegetation on all accounts.

Figure 39. External Obstruction Interference (Vegetation) 5600.



4.3.3 Conclusion

4.3.3.1 Glass

Both instruments showed a large decrease in accuracy as distance increases. This is most evident for the glass placed at 10m from the instrument. For the shorter stations the super prism measured much better than that of the 360 prism. The difference is less noticeable over the stations of 400 and 750m. Both instruments showed large gross errors for measuring direct reflex measuring to the interfering object.

4.3.3.2 Mesh

The S6 proved much better accuracy with interference of the mesh than the 5600. Both showed a trend of as distance increases so does the inaccuracies that occur. This result also confirms the trend shown by Voegtle and Wakaluk (2009). Their experiment tested effects on the measurements of the terrestrial laser scanner HDS 6000 (Leica) caused by different object materials, the distance measured for Voegtle and Wakaluk tests were much shorter but showed quite clearly that iron plates had a continued decrease in accuracy as the distance increased.

No clear trend occurred whether the super prism or 360 prisms measured better with the interference. Both instruments showed large gross errors for measuring direct reflex measuring to the interfering object.

4.3.3.3 Vegetation

The s6 instrument measured much more accurately over the shorter distances with smaller inaccuracy, yet larger fluctuation between positions of the mesh in relation to the target. For the distance of 400m and 750m the older 5600 instrument measured most accurately. Both instruments failed to read with the vegetation at 10m from the instrument, for the station of 750 m. Both instruments showed large gross errors for measuring direct reflex measuring to the interfering object.

4.4 Errors with Experiments

4.4.1 Interference

The setting location of the sign and tail lights were placed so that full view of the prism was not obstructed. It was found that if obstruction of the prism was caused by the retro-reflective object, then the object would be measured. This was regardless of whether the total station was in prism or direct reflex measurement mode. This was found at testing with the sign and taillight assembly at 10m from the instrument. Obstruction testing for the sign and tail lights was not tested at other ranges.

It would be interesting to investigate these as a background as well.

4.4.2 Background

The range for the water background experiment was only 100m in length due to geographical location. At this distance only 3 different measurement ranges were completed. As the experiment only consisted of 3 different ranges, trends in the data are not verified adequately to state an accurate and conclusive result. The testing of the water was always in the background. Would have liked to test water in between, but uncertain on procedures to measure a true distance without water interfering.

4.4.3 Obstruction

The main problem with the obstruction tests is that with the object being moved it is not certain that the obstruction for each station was the same. E.g. with vegetation perhaps more leaves obstructed station @25m than that of 100m would this lead to a change in results?

Chapter 5 Conclusions and Recommendations

From the previous experiment, it can be concluded that for

- Measuring with retro reflective objects
  - When measuring with retroreflective objects near or on line of sight, the Super prism should be measured to, which produced a higher accuracy over the 360 prism.
  - A problematic distance of 100-200m when measuring to the 360 prism was found to yield erroneous results with the retroreflective sign providing interference.
- Measurements for water in the background,
  - The Trimble S6 provided best results over the shorter distances and longer ranges were more accurate with the 5600 total station.
  - Both instruments recorded more accurate results using the super prism over the 360 prism.
- Measuring with obstructions
  - All results with the obstruction test recorded and a decrease in accuracy with an increase of distance,- excluding the case of vegetation with the 5600 instrument
  - Glass resulted in the least accurate measurements of the obstruction, with a clear trend showing the closer the obstruction to the instrument the more error reflected into the measurement.
  - The super prism measured much better results than the 360 prism over the shorter distances (25-200m) and minimal differences between the two at 400m and 750m stations.

Future studies would be interesting to investigate whether the errors found through the experiments are still problematic with the latest instruments. The S7 from Trimble was intended to be tested but due to time limitations not able to be completed. Investigation into whether these errors are found with the process of using the imagining instruments e.g. Trimble VISION™ technology.

All objects were placed perpendicular to line of sight, would results change if the angle of the interfering object was changed? This would be speculated, especially in the case of measuring through the glass plane, that changes in error would result.

Better results were found with the super prism than the 360 prism over the shorter ranges (25m-200m) for the majority of the experiments. However Trimble (2005) states

To achieve the highest accuracy when measuring distances shorter than 200 meters and using the Tracker unit you need to be aware of the following: Always use the Miniature Prism (mounted on your RMT. If you use a large reflector like the Super Prism, reflections from the Tracker unit may have influence on the measured distance. The error can vary from 0 to 3 mm. This error doesn’t occur using the Miniature Prism.

Therefore it would also be beneficial to test how these measurements are effected with the tracking mode in use both with and without the tracking diodes activated.

References

Department of Natural Resources and Mines. (2015). Cadastral Survey Requirements Version 7.0 Retrieved May 1, 2015 from https://www.dnrm.qld.gov.au/?a=105601

Eriksson M. (2014). Accuracy and precision analysis of total station measurements. (Thesis, KTH ROYAL INSTITUTE OF TECHNOLOGY). Retrieved June 17, 2015, from http://www.diva-portal.se/smash/get/diva2:727374/FULLTEXT01.pdf

Henderson, T. (2015). Specular-vs-Diffuse-Reflection. Retrieved June 1, 2015 from http://www.physicsclassroom.com/class/refln/Lesson-1/Specular-vs-Diffuse-Reflection

Inland GPS. (ND). Trimble 5600 Total Station. Retrieved May 15, 2015, http://www.inlandgps.com/ProductDetail.php?sid=&ProductID=29

Jurovich Surveying. (2015). What is a total station? Retrieved July 21, 2015, http://www.jurovichsurveying.com.au/faq/what-is-a-total-station

Kennie, T. J. M. (1983). Some tests of retro-reflective materials for electro-optical distance measurements. *Survey Review*, *27* (208), 51-61.

Kowalczyk, K., & Rapinski, J. (2014). Investigating the Error Sources in Reflector-less EDM. *Journal of Surveying Engineering*, *140*(4).

Lang, S.J. (1980) Correspondence with AGA Geotronics

Leica Geosystems AG. (2008). *Leica FlexLine TS02/TS06/TS09 User Manual.* DOI: 766166-1.0.0en

Litchi D, Gordon S and Tipdecho T. (2005) “Error Models and Propagation in Directly Georeferenced Terrestrial Laser Scanner Networks” Journal of Surveying Engineering 131 (4) 135-142 DOI: 10.1061/ASCE0733-94532005131:4135

Murray & Assoc. (2015). SAFE WORK METHOD STATEMENT - C53802 - SWMS - Rev 00

Pesci, A., Teza, G., 2008. Terrestrial laser scanner and retro-reflective targets: An experiment for anomalous effects investigation. International Journal of Remote Sensing, 29 (19) pp. 5749-5765.

Riegl (2002). "The reflection coefficients of some materials". Retrieved June 1, 2015 from http://www.riegl.com/uploads/tx_pxpriegldownloads/General-Information-Distancemeter.pdf July 2, 2015.

Steyn, N. (2009). Automated methods of precise surveying using robotic total stations and retro reflective tape targets, University of KwaZulu-Natal, Durban,.Retrieved May 25, 2015, from http://geomatics.ukzn.ac.za/Uploads/0090ba64-939c-4057-bfcf-1f107a284e93/STEYN.pdf

Trimble Navigation Limited. (2004).TRIMBLE 5600 DR 300+ TOTAL STATION. DOI: TID 12412D (11/04)

Trimble Navigation Limited. (2005). DIRECT REFLEX EDM TECHNOLOGY FOR THE SURVEYOR AND CIVIL ENGINEER. Retrieved May 05, 2015, from http://trl.trimble.com/docushare/dsweb/Get/Document208582/022543010D_TrimbleS6_DR_WP_1104_lr.pdf

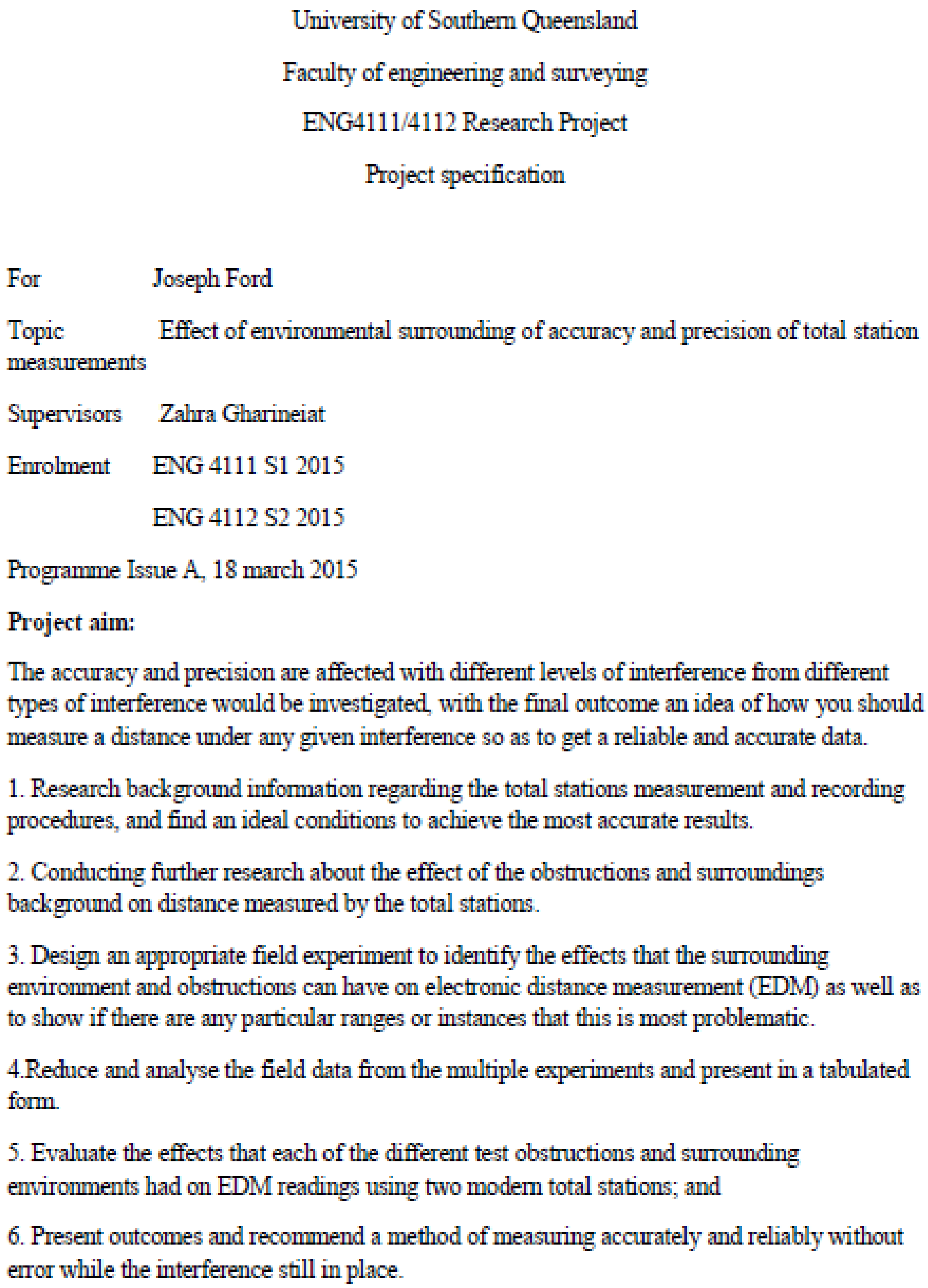
Trimble Navigation Limited. (2013). TRIMBLE S6 TOTAL STATION DATASHEET. DOI: 022543-098L (06/13)

Trimble Navigation Limited. (2015). Trimble S6 Total Station. Retrieved May 15, 2015, http://www.trimble.com/Survey/trimbles6.aspx

Voegtle, T., & Wakaluk, S. (2009). Effects on the measurements of the terrestrial laser scanner HDS 6000 (Leica) caused by different object materials. *Proceedings of ISPRS Work*, *38*, 68-74.

Weyman-Jones, A. (2010). An investigation into the accuracy and limitations of automatic target recognition in total stations. (Thesis, University of Southern Queensland, Australia).Retrieved March 3, 2015, from https://eprints.usq.edu.au/18405/1/Weyman-Jones_2010.pdf

Appendices A – Project Specification



University of Southern Queensland

Faculty of engineering and surveying

ENG4111/4112 Research Project

Project specification

For Joseph Ford

Topic Effect of environmental surrounding of accuracy and precision of total station measurements

Supervisors Zahra Gharineiat

Enrolment ENG 4111 S1 2015

ENG 4112 S2 2015

Programme Issue A, 18 march 2015

Project aim:

The accuracy and precision are affected with different levels of interference from different types of interference would be investigated, with the final outcome an idea of how you should measure a distance under any given interference so as to get a reliable and accurate data.

1. Research background information regarding the total stations measurement and recording procedures, and find an ideal conditions to achieve the most accurate results.

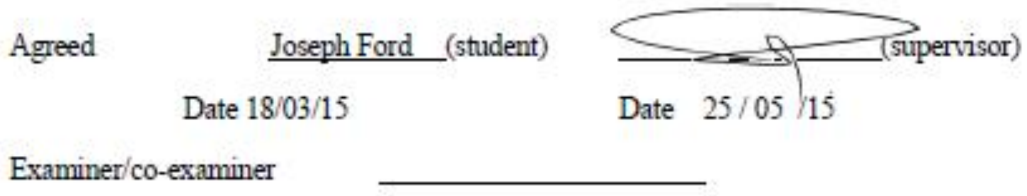
2. Conducting further research about the effect of the obstructions and surroundings background on distance measured by the total stations.

3. Design an appropriate field experiment to identify the effects that the surrounding environment and obstructions can have on electronic distance measurement (EDM) as well as to show if there are any particular ranges or instances that this is most problematic.

4.Reduce and analyse the field data from the multiple experiments and present in a tabulated form.

5. Evaluate the effects that each of the different test obstructions and surrounding environments had on EDM readings using two modern total stations; and

6. Present outcomes and recommend a method of measuring accurately and reliably without error while the interference still in place.



Agreed Joseph Ford (student) (supervisor)

Date 18/03/15 Date 25 / 05 /15

Examiner/co-examiner

Appendices B -Tabulated results of field experiments

Experiment 1 External Retro Reflective Interference of Intended Prism/360 Prism Measurement

Sign

Table 3. External Retro Reflective Interference (Sign) S6.

WITH SIGN INTERFERENCE AT 10M FROM INSTRUMENT

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.001	0.001	25.002	0.002
3.000	49.972	0.000	49.972	0.000
4.000	100.027	0.001	100.030	0.004
5.000	200.014	0.001	200.016	0.003
6.000	399.990	0.000	399.992	0.002
7.000	749.999	0.002	750.000	0.003

WITH SIGN INTERFERENCE AT 1/2 WAY

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.001	0.001	25.002	0.002
3.000	49.972	0.000	49.972	0.000
4.000	100.026	0.000	100.029	0.003
5.000	200.014	0.001	200.015	0.002
6.000	399.991	0.001	399.990	0.000
7.000	749.997	0.000	749.999	0.002

WITH SIGN INTERFERENCE AT 10M FROM TARGET

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.001	0.001	25.002	0.002
3.000	49.971	-0.001	49.972	0.000
4.000	100.027	0.001	100.029	0.003
5.000	200.013	0.000	200.015	0.002
6.000	399.989	-0.001	399.990	0.000
7.000	749.999	0.002	749.999	0.002

Table 4. External Retro Reflective Interference (Sign) 5600.

WITH SIGN INTERFERENCE AT 10M FROM INSTRUMENT

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.001	0.001	25.003	0.003
3.000	49.973	0.001	49.972	0.000
4.000	100.027	0.001	100.029	0.003
5.000	200.014	0.001	200.016	0.003
6.000	399.990	0.000	399.991	0.001
7.000	749.998	0.001	749.999	0.002

WITH SIGN INTERFERENCE AT 1/2 WAY

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.001	0.001	25.003	0.003
3.000	49.972	0.000	49.972	0.000
4.000	100.027	0.001	100.029	0.003
5.000	200.013	0.000	200.015	0.002
6.000	399.990	0.000	399.991	0.001
7.000	749.998	0.001	749.999	0.002

WITH SIGN INTERFERENCE AT 10M FROM TARGET

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.001	0.001	25.003	0.003
3.000	49.972	0.000	49.971	-0.001
4.000	100.026	0.000	100.029	0.003
5.000	200.013	0.000	200.016	0.003
6.000	399.989	-0.001	399.991	0.001
7.000	749.998	0.001	749.999	0.002

Tail Light Assembly

Table 5. External Retro Reflective Interference (Tail Light Assembly) S6.

TAIL LIGHT ASSEMBLYS AT 10M FROM INSTRUMENT

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.000	0.000	25.002	0.002
3.000	49.972	0.000	49.970	-0.002
4.000	100.025	-0.001	100.031	0.005
5.000	200.013	0.000	200.014	0.001
6.000	399.990	0.000	399.992	0.002
7.000	749.998	0.001	749.998	0.001

TAIL LIGHT ASSEMBLYS AT 1/2 WAY

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.000	0.000	25.002	0.002
3.000	49.972	0.000	49.969	-0.003
4.000	100.026	0.000	100.027	0.001
5.000	200.012	-0.001	200.015	0.002
6.000	399.991	0.001	399.991	0.001
7.000	749.995	-0.002	749.995	-0.002

TAIL LIGHT ASSEMBLYS AT 10M FROM TARGET

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.000	0.000	25.002	0.002
3.000	49.970	0.001	49.971	-0.001
4.000	100.028	0.002	100.028	0.002
5.000	200.011	-0.002	200.014	0.001
6.000	399.991	0.001	399.991	0.001
7.000	749.997	-0.002	749.995	-0.003

Table 6. External Retro Reflective Interference (Tail Light Assembly) 5600.

TAIL LIGHT ASSEMBLY AT 10M FROM INSTRUMENT

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.000	0.000	25.003	0.003
3.000	49.973	0.001	49.971	-0.001
4.000	100.025	-0.001	100.030	0.004
5.000	200.014	0.001	200.016	0.003
6.000	399.989	-0.001	399.992	0.002
7.000	749.999	0.002	749.998	0.001

TAIL LIGHT ASSEMBLY AT 1/2 WAY

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.000	0.000	25.003	0.003
3.000	49.971	-0.001	49.970	-0.002
4.000	100.026	0.000	100.028	0.002
5.000	200.013	0.000	200.016	0.003
6.000	399.991	0.001	399.992	0.002
7.000	749.996	-0.001	749.996	-0.001

TAIL LIGHT ASSEMBLY AT 10M FROM TARGET

STATION	SUPER PRISM	DIFERENCE	360 PRISM	DIFERENCE
2.000	25.000	0.000	25.003	0.003
3.000	49.971	-0.001	49.970	-0.002
4.000	100.028	0.002	100.028	0.002
5.000	200.013	0.000	200.015	0.002
6.000	399.991	0.001	399.991	0.001
7.000	749.997	0.000	749.995	-0.002

Experiment 2 External Background (Water) Interference of Intended Prism/360 Prism Measurement

Table 7 External Background (Water) Interference S6

25m

MODE	DISTANCE	DIFF
PRISM STANDARD MODE	24.844	0.001
360 PRISM	24.845	0.002
DR	24.847	0.004
50m		
MODE	DISTANCE	DIFF
PRISM STANDARD MODE	49.652	0.002
360 PRISM	49.654	0.004
DR	49.653	0.003
100m		
MODE	DISTANCE	DIFF
PRISM STANDARD MODE	99.356	0.001
360 PRISM	99.359	0.004
DR	99.360	0.005

Table 8. External Background Interference (Water) 5600.

25m

		DIFF
PRISM STANDARD MODE	24.837	-0.005
360 PRISM	24.836	-0.006
DR	24.847	-0.005
50m		
		DIFF
PRISM STANDARD MODE	49.648	-0.003
360 PRISM	49.650	-0.001
DR	49.650	0.001
100m		
		DIFF
PRISM STANDARD MODE	99.356	0.000
360 PRISM	99.356	0.000
DR	99.346	-0.009

Experiment 3 External Obstruction Interference of Intended Prism/360 Prism Measurement

Glass

Table 9. External Obstruction Interference (Glass) S6.

GLASS AT 10M FROM INSTRUMENT

STN	SUPER PRISM	DIFFERENCE	360 PRISM	DIFFERENCE	DIRECT REFLEX	DIFFERENCE
2	25.002	0.000	25.005	0.003	11.132	-13.870
3	49.970	0.001	49.975	0.005	49.970	0.001
4	100.030	0.003	100.032	0.005	100.035	0.008
5	200.022	0.008	200.023	0.009	COULD NOT READ	
6	399.999	0.007	400.000	0.009		
7	750.011	0.010	749.998	-0.003		
GLASS AT 1/2 WAY						
STN	SUPER PRISM	DIFFERENCE	360 PRISM	DIFFERENCE	DIRECT REFLEX	DIFFERENCE
2	25.002	0.000	25.005	0.003	11.132	-13.870
3	49.960	-0.009	49.974	0.005	24.856	-25.113
4	100.028	0.001	100.031	0.004	50.203	-49.824
5	200.016	0.002	200.018	0.004	120.028	-79.986
6	399.989	-0.003	399.991	-0.001	COULD NOT READ	
7	749.9943094	-0.007	749.994709	-0.006		
GLASS AT 10M FROM TARGET						
STN	SUPER PRISM	DIFFERENCE	360 PRISM	DIFFERENCE	DIRECT REFLEX	DIFFERENCE
2	25.002	0.000	25.005	0.003	11.132	-13.870
3	49.961	-0.008	49.973	0.004	42.114	-7.855
4	100.028	0.001	100.032	0.005	90.201	-9.826
5	200.016	0.002	200.018	0.004	192.720	-7.294
6	399.988	-0.004	399.990	-0.002	COULD NOT READ	
7	749.995	-0.006	749.996	-0.005		

Table 10. External Obstruction Interference (Glass) 5600.

GLASS AT 10M FROM INSTRUMENT

STN	SUPER PRISM	DIFFERENCE	360 PRISM	DIFFERENCE	DIRECT REFLEX	DIFFERENCE
2.000	25.003	0.001	25.005	0.003	25.002	0.001
3.000	49.969	-0.002	49.972	0.002	49.970	0.000
4.000	100.030	0.002	100.034	0.007	100.034	0.007
5.000	200.020	0.006	200.022	0.008	COULD NOT READ	
6.000	400.000	0.008	400.001	0.009		
7.000	750.011	0.009	750.013	0.011		

GLASS AT 1/2 WAY

STN	SUPER PRISM	DIFFERENCE	360 PRISM	DIFFERENCE	DIRECT REFLEX	DIFFERENCE
2.000	25.003	0.001	25.005	0.003	25.002	0.001
3.000	49.970	0.001	49.975	0.006	25.223	-24.746
4.000	100.027	0.000	100.031	0.004	50.673	-49.354
5.000	200.015	0.001	200.018	0.004	100.033	-99.981
6.000	399.989	-0.003	399.992	0.000	COULD NOT READ	
7.000	749.994	-0.007	749.995	-0.006		

GLASS AT 10M FROM TARGET

STN	SUPER PRISM	DIFFERENCE	360 PRISM	DIFFERENCE	DIRECT REFLEX	DIFFERENCE

2.000	25.003	0.001	25.005	0.003	25.002	0.001
3.000	49.971	0.002	49.973	0.004	40.761	-9.208
4.000	100.027	0.000	100.031	0.004	90.071	-9.956
5.000	200.016	0.002	200.017	0.003	COULD NOT READ	
6.000	399.988	-0.004	399.991	-0.001		
7.000	749.994	-0.007	749.996	-0.005		

Mesh

Table 11. External Obstruction Interference (Mesh) S6.

MESH 10 m FROM INSTRUMENT

STATION	PRISM	DIFF	360 PRISM	DIFF
2	25.001	0.001	25.001	0.001
3	49.966	-0.002	49.969	0.001
4	100.026	-0.001	100.027	0.000
5	200.013	-0.001	200.013	-0.001
6	399.991	-0.001	399.992	0.000
7	750.000	-0.002	750.003	0.001

MESH 1/2 WAY				
STATION	PRISM	DIFF	360 PRISM	DIFF
2	25.001	0.001	25.001	0.001
3	49.968	0.000	49.969	0.001
4	100.027	0.000	100.029	0.002
5	200.014	0.000	200.016	0.002
6	399.992	0.000	399.993	0.001
7	750.000	-0.002	750.000	-0.002
MESH 10 m FROM TARGET				
STATION	PRISM	DIFF	360 PRISM	DIFF
2	25.001	0.001	25.001	0.001
3	49.969	0.001	49.970	0.002
4	100.027	0.000	100.028	0.001
5	200.014	0.000	200.017	0.003
6	399.992	0.000	399.993	0.001
7	750.002	0.000	750.004	0.002

Table 12. External Obstruction Interference (Mesh) 5600.

MESH 10M FROM INSTRUMENT

STN	PRISM	DIFF	360	DIFF
2	25.000	-0.001	25.001	0.000
3	49.969	0.000	49.971	0.002
4	100.027	0.000	100.026	-0.001
5	200.015	0.001	200.013	-0.001
6	399.991	-0.003	399.992	-0.002
7	750.002	-0.003	750.002	-0.003
MESH 1/2 WAY				
STN	PRISM	DIFF	360	DIFF
2	25.000	-0.001	25.001	0.000
3	49.970	0.001	49.972	0.003
4	100.027	0.000	100.027	0.000
5	200.013	-0.001	200.016	0.002
6	399.992	-0.002	399.993	-0.001
7	750.000	-0.005	750.000	-0.005
MESH 10M FROM TARGET				
STN	PRISM	DIFF	360	DIFF
2	25.000	-0.001	25.001	0.000
3	49.969	0.000	49.970	0.001
4	100.026	-0.001	100.026	-0.001
5	200.013	-0.001	200.015	0.001
6	399.993	-0.001	399.993	-0.001
7	750.000	-0.005	750.003	-0.002

Vegetation

Table 13. External Obstruction Interference (Vegetation) S6.

VEGETATION 10 m FROM INSTRUMENT

STATION	PRISM	DIFF	360 PRISM	DIFF
2	24.998	-0.002	24.996	-0.004
3	49.969	0.000	49.969	0.000
4	100.029	0.000	100.029	0.000
5	200.022	0.001	200.026	0.005
6	399.995	-0.002	399.998	0.001
7	750.003	-0.005	750.004	-0.004
VEGETATION 1/2 WAY				
STATION	PRISM	DIFF	360 PRISM	DIFF
2	24.998	-0.002	24.996	-0.004
3	49.968	-0.001	49.972	0.003
4	100.028	-0.001	100.032	0.003
5	200.019	-0.002	200.021	0.000
6	399.991	-0.006	399.993	-0.004
7	750.002	-0.006	750.004	-0.004
VEGETATION 10 m FROM TARGET				
STATION	PRISM	DIFF	360 PRISM	DIFF
2	24.998	-0.002	24.996	-0.004
3	49.967	-0.002	49.970	0.001
4	100.026	-0.003	100.035	0.006
5	200.018	-0.003	200.022	0.001
6	399.992	-0.005	399.990	-0.007
7	COULD NOT READ			

Table 14. External Obstruction Interference (Vegetation) 5600.

VEGETATION 10m FROM INSTRUMENT

STATION	PRISM	DIFF	360 PRISM	DIFF
2	25.001	0.002	25.002	0.003
3	49.971	0.002	49.965	-0.004
4	100.027	0.000	100.028	0.001
5	200.016	0.001	200.017	0.002
6	399.992	0.001	399.993	0.002
7	750.002	-0.002	750.002	-0.002
VEGETATION 1/2 WAY				
STATION	PRISM	DIFF	360 PRISM	DIFF
2	25.001	0.002	25.002	0.003
3	49.964	-0.005	49.971	0.002
4	100.029	0.002	100.029	0.002
5	200.020	0.005	200.016	0.001
6	399.993	0.002	399.994	0.003
7	750.003	-0.001	COULD NOT READ	
VEGETATION 10m FROM TARGET				
STATION	PRISM	DIFF	360 PRISM	DIFF
2	25.001	0.002	25.002	0.003
3	49.969	0.000	49.971	0.002
4	100.029	0.002	100.032	0.005
5	200.019	0.004	200.019	0.004
6	399.994	0.003	399.991	0.000
7	COULD NOT READ			

Appendices C – Risk Assessment

Risk Assessment Matrix Tool

Risk Matrix		**Consequence (C)**				
		1. Insignificant	2. Minor	3. Moderate	4. Major	5. Catastrophic
Likelihood (L)	A. Almost Certain	15. High	10. High	6. Critical	3. Critical	1. Critical
	B. Probable	19. Medium	14. High	9. High	5. Critical	2. Critical
	C. Possible	22. Low	18. Medium	13. High	8. Critical	4. Critical
	D. Unlikely	24. Low	21. Low	17. Medium	12. High	7. Critical
	E. Very Unlikely	25. Low	23. Low	20. Medium	16. High	11. High

Acceptable	**Acceptable with strict controls**		**Un-acceptable**
Low	Medium	High	Critical

Likelihood (L)	
A	Very likely, may occur daily
B	Highly likely, may occur every week
C	Quite possible, may occur 2-3 months
D	Not expected, may occur once a year
E	Only in exceptional circumstances.

Table 15. Risk Assessment Matrix Tool.

Table 16. Consequence Assessment Tool.

Level	**Descriptor**	**Complaints**	**Variation from Contract Specification**	**Cost of Corrective Action**	**Key Service Delivery Outcomes Jeopardised**	**Litigation Potential**	**Loss of Market Access**	**Environmental Impact**	**Injury or Damage to Employee, Public or Property**
1	**Insignificant**	Unlikely	None	Cost not visible	No	None	None	None	• First aid treatment injury only • Incident resulting in momentary work

								stoppage, less than $5K
2 Minor	Minor verbal complaint likely	Minor variation	Resolved locally by Company Management	Not of any consequence	None	None	Some minor contamination of soil, water, air, flora, fauna which is easily and effectively rectified	• Injury requiring medical treatment without loss of a full day • Minor loss or damage to property, between $5K - $50K
3 Moderate	Written complaint certain	Noticeable variation	Resource allocation by Company Management (within budget)	Some outcomes not achieved	Successful litigation unlikely	Minor affect	Minor contamination of soil, water, air, flora, fauna or humans that is well within the ability and resources of the company to rectify	• Injury requiring medical treatment resulting in one or more days off work • Moderate loss or damage to property, between $50K - $100K
4 Major	Significant verbal and written complaint/s certain	Significant variation	High cost of resource allocation (outside budget)	Key outcomes jeopardised	Litigation likely	Moderate affect	Contamination of soil, water air, flora, fauna or humans that requires significant resources to rectify	• Long term illness or serious injury • Major loss or damage to property, between $100K - $500K
5 Catastrophic	Significant complaints made publicly	Significant unjustifiable variation with serious implications	Significant resource allocation with very high cost of corrective action	Key product and service delivery outcomes not achieved	Successful litigation almost certain to follow	Significant affect	Significant and EPA reportable contamination of soil, water, air, flora, fauna or humans requiring significant resources beyond the ability of the company to rectify	• Death or permanent disability • Significant loss or damage to property, more than

🟥								$500K

#	Job step Break down into logical steps	Potential hazard Identify the actual and potential hazards	Legislative requirements	Initial risk			Control Measures What will eliminate / reduce the risk (in line with the hierarchy of control)	Residual risk			Person responsible
				C	L	R		C	L	R	
1.	Developing SWMS, JSEA and WHS	Not involving all work team members in identifying possible hazards	Work Health & Safety Act and Regulation 2011, How to Manage Work Health and Safety Risks Code of Practice 2011, Work Health and Safety Consultation, Co-operation and Co-ordination Code of Practice 2011	4	C	8	All work team members shall participate in the development of the SWMS or JSEA sign on	3	D	17	WHS, Supervisor, Surveyor and field assistant/s
2.	Getting to site (driving) and driving on site.	Traffic accident Livestock Fences and gates Terrain (ruts and washouts) Dust Spread of weed Emergency evacuation Other on site vehicles, machines and operators	Transport Infrastructure Act 1994 Traffic Road Rules, Work Health & Safety Act and Regulation 2011	3	D	17	Hold current drivers licence. Comply with road rules. Not to be under the influence of drugs or alcohol. Break long drives every 2 hours. Ensure vehicle is roadworthy. Do not use mobile phone when driving. Be observant and aware of wildlife and livestock. Be mindful of speed on dirt roads. When using gate, ensure vehicle is in gear and motor turned off and handbrake is engaged. Ensure vehicle is clean to prevent spread of noxious weed. Ensure training in site specific vehicle and communication requirements (see SOP MA045 Fatigue	2	E	23	Driver and passenger

#	Job step Break down into logical steps	Potential hazard Identify the actual and potential hazards	Legislative requirements	Initial risk			Control Measures What will eliminate / reduce the risk (in line with the hierarchy of control)	Residual risk			Person responsible
				C	L	R		C	L	R	
							Mmgt & vehicle safety, SOP MA069 Local Vehicle travel)				
3.	Parking and unloading	Manual Handling injury	Work Health & Safety Act and Regulation 2011, Hazardous Manual Tasks Code of Practice 2011	3	D	17	Do not lift by bending your back; do not lift heavy loads by yourself. Avoid awkward postures. (See SOP MA051 Manual Handling Tasks). PPE: steel capped boots, safety glasses, gloves, high.vis clothing.	2	E	23	Surveyor and field assistant/s
4.	Set up survey equipment	Survey equipment may connect with fences, power lines and windmill. Setting up on uneven ground may result in slips/ trips and damaged equipment.	Work Health & Safety Act and Regulation 2011,	4	C	8	Follow on site rules, use gate if possible and leave as found. Look up and assess BEFORE setting up gear. Be observant of ground conditions, and sure footed. (See SOP MA068 setting up GPS station, and SOP MA067 General Survey work). PPE: steel capped boots, safety glasses, gloves, high.vis clothing, hard hat (if req).	D	3	17	Surveyor and field assistant/s
5.	Surveying	Non observance of restriction regarding the clearing of vegetation at the work site.	Natural Asset Local Law 2003	3	D	17	Vegetation can only be pruned or trimmed if the line of sight is obscured or where access to the site feature is obstructed. Leaves and branches can be removed using hand equipment and ensuring that cuts are neat (AS4373-2008-Pruning of Amenity Trees). Vegetation is to be tied back where	2	E	23	Surveyor and field assistant/s

#	Job step Break down into logical steps	Potential hazard Identify the actual and potential hazards	Legislative requirements	Initial risk			Control Measures What will eliminate / reduce the risk (in line with the hierarchy of control)	Residual risk			Person responsible
				C	L	R		C	L	R	
							possible so that cutting of tree limbs is avoided. Long grass can be cleared to permit access to the survey stations and site features.				
6.	Surveying	Sun exposure, heat stress/sun stroke, fatigue, dehydration	Work Health & Safety Act 2011 Work Health & Safety Consultation, Cooperation and Coordination Code of Practice.	3	C	13	Mandatory PPE for outdoor work are broad brimmed hat, sun glasses, long sleeves and long pants. Cover exposed skin with sun block every 2 to 3 hours. Take regular rest breaks, plan work breaks in advance and ensure meals are stored appropriately in esky. Rest in vehicle or shade. Drink plenty of water. PPE: steel capped boots, safety glasses, gloves, high.vis clothing, hard hat (if req).	2	E	23	Surveyor and field assistant/s
7.	Moving about the work area	Slips Trips Falls from walking on uneven ground. Sharp sticks and logs Fences	Work Health & Safety Act 2011 Work Health & Safety Consultation, Cooperation and Coordination Code of Practice.	2	C	18	Be surefooted and watch where you are walking. Walk around uneven ground, logs and sticks. Stay away from fences where possible. Ensure communication is accessible. PPE: steel capped boots, safety glasses, clothing, hard hat (if req).	2	E	23	Surveyor and field assistant/s
8.	Moving about the work area	Bite from snakes and wildlife interaction Tick bite	Work Health & Safety Act 2011 Work Health & Safety Consultation, Cooperation and Coordination Code of	2	C	18	Be mindful of wildlife. Walk along the centre of stock tracks; avoid long grass and areas where stock gather. Use insect repellent containing deet. Wear long sleeved shirt, long pants and a wide brimmed hat. Inspect skin regularly.	2	E	23	Surveyor and field assistant/s

#	Job step Break down into logical steps	Potential hazard Identify the actual and potential hazards	Legislative requirements	Initial risk			Control Measures What will eliminate / reduce the risk (in line with the hierarchy of control)	Residual risk			Person responsible
				C	L	R		C	L	R	
			Practice.				Ensure first aid equipment is stocked and accessible, ensure communication is accessible. PPE: steel capped boots, safety glasses, clothing, hard hat (if req).				
9.	Moving about the work area	Hazard to worker and equipment from other vehicle and machinery movement on adjacent roads.	Work Health & Safety Act and Regulation 2011, Traffic Management for Construction or Maintenance Work Code of Practice 2008, TMR Manual of uniform traffic control devices Pt3 2010	3	C	13	Survey work alongside Waterworks Rd or other roads to be 3 to 6m clear of moving traffic. Assess volume of traffic and duration of survey work required alongside any moving vehicles to determine if signage is required. PPE: steel capped boots, safety glasses, clothing, and hard hat.	3	D	17	
10.	Survey marking	Hazardous chemicals Inhaling spray paint vapour Hammer pinch injury Underground services	Work Health & Safety Act 2011 Work Health & Safety Consultation, Cooperation and Coordination Code of Practice. Hazardous Chemicals Codes of Practice 2011	2	C	18	Use spray paints in ventilated area, apply safety advice as per SDS, wear safety glasses, mask and protective high vis. clothing. Use PPE (gloves) when using hammer tools. Visually inspect site for underground service location, place peg no deeper than 300mm. (see SOP MA047 Handling hazardous chemicals, SOP MA082 Slide Hammer Use). Additional PPE: steel capped boots, hard hat (if req).	2	E	23	Surveyor and field assistant/s
11.	Weather conditions	Storms	Work Health & Safety	4	C	8	Discontinue work if any sign of storm.	2	C	18	Surveyor and field

#	Job step Break down into logical steps	Potential hazard Identify the actual and potential hazards	Legislative requirements	Initial risk			Control Measures What will eliminate / reduce the risk (in line with the hierarchy of control)	Residual risk			Person responsible
				C	L	R		C	L	R	
		Rain Wind Lightning strike Bush fire	Act 2011 Work Health & Safety Consultation, Cooperation and Coordination Code of Practice.				Shelter in vehicle, away from tall timber. Follow safety alert notices. Ensure training in site evacuation procedure. Ensure open communication channels				assistant/s
12.	Site housekeeping	Rubbish left on site causing tripping hazard and injury to livestock and wildlife. Damage to environment.	Work Health & Safety Act 2011 Work Health & Safety Consultation, Cooperation and Coordination Code of Practice.	2	C	18	Take all rubbish with you and pick up any minor rubbish as required	1	E	25	Surveyor and field assistant/s

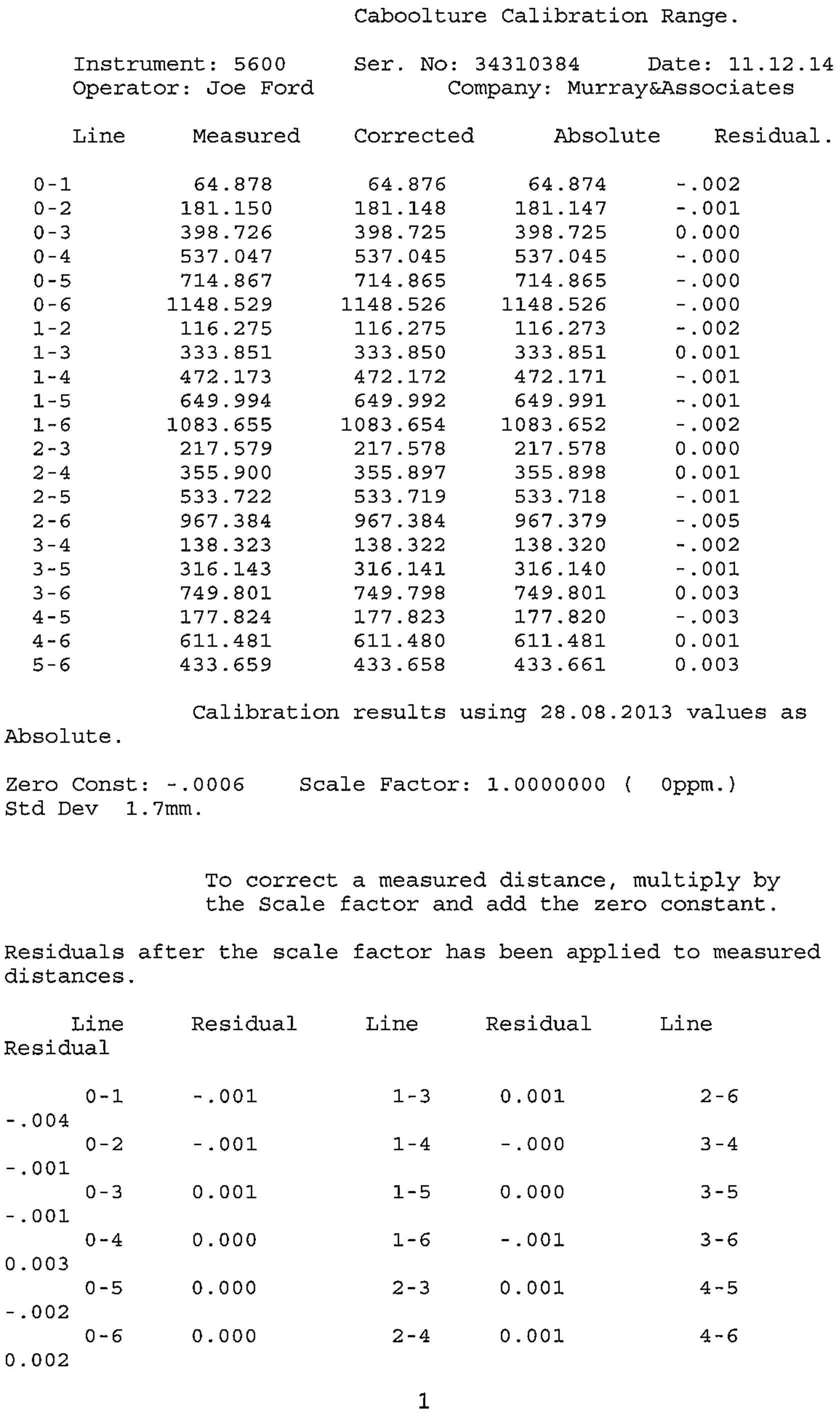
Workers' declaration:

I have been instructed in the Safe Work Procedures as outline in this Safe Work Method Statement. I clearly understand my responsibilities and that failure to comply with the instruction will lead to disciplinary action, which may result in dismissal.

Name (Block letters)	Signature	Date

(Murray & Assoc, 2015)

Appendices D – Calibration Reports



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                         Caboolture Calibration Range.

     Instrument: 5600     Ser. No: 34310384     Date: 11.12.14
     Operator: Joe Ford          Company: Murray&Associates

     Line      Measured    Corrected       Absolute    Residual.

  0-1          64.878       64.876       64.874     -.002
  0-2         181.150      181.148      181.147     -.001
  0-3         398.726      398.725      398.725     0.000
  0-4         537.047      537.045      537.045     -.000
  0-5         714.867      714.865      714.865     -.000
  0-6        1148.529     1148.526     1148.526     -.000
  1-2         116.275      116.275      116.273     -.002
  1-3         333.851      333.850      333.851     0.001
  1-4         472.173      472.172      472.171     -.001
  1-5         649.994      649.992      649.991     -.001
  1-6        1083.655     1083.654     1083.652     -.002
  2-3         217.579      217.578      217.578     0.000
  2-4         355.900      355.897      355.898     0.001
  2-5         533.722      533.719      533.718     -.001
  2-6         967.384      967.384      967.379     -.005
  3-4         138.323      138.322      138.320     -.002
  3-5         316.143      316.141      316.140     -.001
  3-6         749.801      749.798      749.801     0.003
  4-5         177.824      177.823      177.820     -.003
  4-6         611.481      611.480      611.481     0.001
  5-6         433.659      433.658      433.661     0.003

              Calibration results using 28.08.2013 values as
Absolute.

Zero Const: -.0006    Scale Factor: 1.0000000 (  0ppm.)
Std Dev  1.7mm.


               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     -.001          1-3     0.001          2-6
-.004
      0-2     -.001          1-4     -.000          3-4
-.001
      0-3     0.001          1-5     0.000          3-5
-.001
      0-4     0.000          1-6     -.001          3-6
0.003
      0-5     0.000          2-3     0.001          4-5
-.002
      0-6     0.000          2-4     0.001          4-6
0.002

                              1
```

```
        1-2      -.001           2-5      -.001           5-6
0.004
```

2

Moreton Bay Regional Council EDM BOOKING SHEET

Company
Surveyor: Joe Ford

Date: 11.12.14

Mets:

EDM Make: S600

Temp. °C

Press. mm/mb ppm

Serial No: 384310384

Prism Const mm

Time:

Observed Dists Slope or [✓ Horiz]

ON OFF

0 - 1	0 - 2	0 - 3	0 - 4	0 - 5	0 - 6
64.878	181.149	398.725	537.047	714.867	1148.527
9	5	7	8	8	30
8	9	7	7	6	0
8	50	6	7	7	0
8	0	5	7	7	29
8	0	7	7	8	9
8	0	6	7	7	30
9	0	5	7	8	0
9	0	6	6	7	9
8	0	7	7	7	9
mean= 64.878	mean= 181.150	mean= 398.726	mean= 537.047	mean= 714.867	mean= 1148.529

1 - 2	1 - 3	1 - 4	1 - 5	1 - 6
116.274	333.852	472.172	649.993	1083.655
4	2	3	3	6
4	1	4	4	4
5	2	4	3	5
5	1	4	4	5
5	2	4	4	5
4	1	3	4	4
5	1	3	3	6
5	1	4	4	5
5	1	3	4	4
mean= 116.275	mean= 333.851	mean= 472.173	mean= 649.994	mean= 1083.655

2 - 3	2 - 4	2 - 5	2 - 6
217.580	355.900	533.722	967.383
80	1	2	5
78	0	1	4
78	1	2	3
79	0	3	4
78	1	2	3
79	0	1	4
78	0	1	3
79	899	1	3
79	0	2	3
mean= 217.579	mean= 355.900	mean= 533.722	mean= 967.384

RESULTS:

Scale Factor

Prism Constant

DI

3 - 4	3 - 5	3 - 6	4 - 5	4 - 6	5 - 6
138.322	316.143	749.802	177.825	611.481	433.658
1	2	1	4	3	8
3	3	1	3	2	9
3	2	1	4	1	8
4	1	1	4	1	9
4	2	0	4	1	8
2	3	1	4	1	9
3	4	1	4	1	60
4	2	2	4	2	8
2	3	1	4	2	9
mean= 138.323	mean= 316.143	mean= 749.801	mean= 177.824	mean= 611.481	mean= 433.659

2/12/2014

Record Mets and input into your EDME @ each Pillar set-up

Caboolture Calibration Range.

Instrument: Trimlbe S6 Ser. No: 93111477 Date: 09/12/14
Operator: Dorin Bora Company: Murray & Associates

Line	Measured	Corrected	Absolute	Residual.
0-1	64.876	64.874	64.874	0.000
0-2	181.146	181.144	181.147	0.003
0-3	398.720	398.719	398.725	0.006
0-4	537.042	537.040	537.045	0.005
0-5	714.862	714.860	714.865	0.005
0-6	1148.527	1148.524	1148.526	0.002
1-2	116.270	116.270	116.273	0.003
1-3	333.845	333.844	333.851	0.007
1-4	472.166	472.165	472.171	0.006
1-5	649.985	649.982	649.991	0.008
1-6	1083.643	1083.642	1083.652	0.010
2-3	217.573	217.572	217.578	0.006
2-4	355.895	355.892	355.898	0.006
2-5	533.715	533.713	533.718	0.005
2-6	967.377	967.377	967.379	0.002
3-4	138.321	138.320	138.320	0.000
3-5	316.140	316.138	316.140	0.002
3-6	749.796	749.793	749.801	0.008
4-5	177.822	177.821	177.820	-.001
4-6	611.482	611.481	611.481	0.000
5-6	433.661	433.660	433.661	0.001

Calibration results using 28.08.2013 values as Absolute.

Zero Const: 0.0023 Scale Factor: 1.0000036 (4ppm.)
Std Dev 2.8mm.

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	-.002	1-3	0.003	2-6	-.003
0-2	-.000	1-4	0.002	3-4	-.002
0-3	0.002				

Moreton Bay Regional Council EDM BOOKING SHEET

Company
Surveyor:
Date: 9 Dec 2014

Doris

EDM Make: TRIMBLE S6
Serial No: 93 111 477

Mets:
Temp. 31 °C
Press. 1015 mm/mb 9 ppm
Prism Const mm

Time:
Observed Dists Slope or Horiz

ON OFF

0 - 1	0 - 2	0 - 3	0 - 4	0 - 5	0 - 6
64.876	181.145	398.719	537.042	714.863	1148.527
6	6	5	1	3	7
6	6	20	2	3	7
6	6	19	2	3	7
5	7	19	2	2	9
6	6	20	1	2	7
6	6	20	1	3	7
6	7	19	1	1	6
6	6	20	2	2	5
6	6	20	1	2	7
mean= 64.876	mean= 181.146	mean= 398.720	mean= 537.042	mean= 714.862	mean= 1148.527

1 - 2	1 - 3	1 - 4	1 - 5	1 - 6
116.271	333.845	472.166	649.986	1083.643
1	4	7	5	3
1	6	6	5	3
0	5	5	6	3
1	5	6	5	2
1	4	4	4	3
0	5	5	6	4
0	6	6	5	3
0	5	6	5	3
0	5	5	6	3
mean= 116.270	mean= 333.845	mean= 472.166	mean= 649.985	mean= 1083.643

2 - 3	2 - 4	2 - 5	2 - 6
217.572	355.895	533.714	967.377
4	5	5	7
3	5	5	7
3	5	5	8
3	4	4	7
3	5	5	8
2	5	4	7
3	5	5	7
3	5	4	7
4	5	4	6
mean= 217.573	mean= 355.895	mean= 533.715	mean= 967.377

RESULTS:

Scale Factor

Prism Constant

3 - 4	3 - 5	3 - 6	4 - 5	4 - 6	5 - 6
138.321	316.140	749.797	177.821	611.483	433.662
1	0	7	2	2	2
1	0	5	2	2	2
2	1	6	2	1	0
1	0	5	2	2	2
2	0	5	3	2	2
1	0	6	2	2	1
1	0	7	1	2	1
2	1	7	2	2	1
1	0	6	2	2	1
mean= 138.321	mean= 316.140	mean= 749.796	mean= 177.822	mean= 611.482	mean= 433.661

Record Mets and input into your EDME @ each Pillar set-up