University of Southern Queensland

Faculty of Engineering and Surveying

Reflector-less Total Station Measurements and their Accuracy, Precision and Reliability.

A dissertation submitted by

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Abstract

Reflector-less Total Station Measurements and their Accuracy, Precision and Reliability.

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Despite the vast technological advancements in equipment, the survey industry continues to struggle with the collection of data relating to inaccessible points. While the introduction of reflector-less total stations has meant that inaccessible points can now be measured with relative ease, there are some questions as to the accuracy and reliability that can be achieved with such equipment.

The object of this study is to determine likely limits for reliability of reflector-less instruments especially in relation to measurements with large angles of incidence, but also looking at the vagaries caused by differing materials and beam divergence. The study has been carried out in various locations using Trimble S6 and S8 reflector-less total station equipment to a variety of surfaces materials and shapes.

This study suggests that angle of incidence of the measurement signal to the surface of the measured material has a large influence on the accuracy of that measurement. In the search for accurate survey results from inaccessible points, it becomes necessary to ensure that crucial measurements are checked as well as having a good understanding of reflector-less instruments capabilities.

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Courses ENG4111and 4112 *Research Project*

Limitations of Use

Certification

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.

Leigh Herbert Coaker

Student Number: Q1221241

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Signature

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Date

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Firstly I'd like to thank Fleur, my wife, of putting up with me being locked away in the office for seeming endless weekends, or 'working' on weekends while collecting field data. Especially then coming home (or out of the office) and complaining about how much quality surf I've missed out on.

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Glossary

Total Station — Surveying instrument combining Electronic Distance Measurement Equipment (EDME) with a digital theodolite and electronic data recording. Measures horizontal and vertical angles and slope distance from which horizontal distance is calculated. Given a known (or arbitrary coordinate), and a bearing, from which to start, coordinates can then be calculated for new positions.

Prism — A glass or plastic reflector that reflects an electro-magnetic signal back to where it originated, even though the angle of incidence may change,

3D cords — (three-dimensional coordinates). Coordinates with X,Y,Z values, generally known as Eastings, Northings and RL (Reduced Level)

EDM or *EDME* — Electronic Distance Measurement or Electronic Distance Measuring Equipment. The term EDM and EDME are often used interchangeably.

CAD — Computer Aided Design. Computer software that greatly reduces the need for hand calculations and design.

Chainman — A survey assistant, used especially where instruments require two people, for instance levelling, total station set-outs and pick-ups (non robotic) as well as helping to dig and chop as required. Also know as a 'chainy'.

Theodelite — very similar to and the predecessor of the total station. Measures accurate horizontal and vertical angles which can be used in conjunction with a measured distance to calculate coordinate data.

reflector-less total station

a total station with in-built reflector-less technology forced centring A surveying technique where the tribrach is left on legs (tripod) when changing between instruments and / or targets. This can eliminate centring errors due to not using the optical plummet on the tribrach.

Tribrach a piece of surveying equipment that connects the tripod (legs) to the instrument or prism

Legs the three legged tripod that is used to setup surveying instruments near eye height.

PPM parts-per-million. A term to describe the effects of atmospherics on the measurement signal, both to a prism and reflector-less. A value of 2ppm indicates that the atmosphere could cause errors of up 2mm per 1000m. Obviously, as the distance decrease, so does the error in slope distance.

Angle of incidence

the angle of between the direction of incoming radiation and the normal to the intercepting surface. (CSIRO, 1992)

Square to the object = normal to the surface = angle of incidence is zero.

1 Project Overview

An investigation into the accuracy, precision and reliability of reflector-less Total Stations.

1.1 Aim

To determine the accuracy, precision and reliability of reflector-less Total Stations when used in situations where perpendicular measurements cannot be taken. The project involves the investigation and identification of potential solutions through the use of surveying techniques and instrument knowledge to improve the dependability of this technology.

1.2 The Problem

Reflector-less (prism-less) technology is used in a variety of situations to survey infrastructure that is inaccessible or unsafe, or as a more efficient work practice. While taking a measurement to a flat, perpendicular surface (perpendicular to the reflector-less signal) is not perceived as an issue, a question of accuracy and reliability is raised when taking measurements to a wall with an angle of incidence of 30 degrees, or 50 degrees.

In addition, measurements to building corners either an internal or external corner could be suspect, depending upon how and where the signal is reflected. As distance from the instrument increases, so does the width of the signal beam. How can we, as surveyors, be confident that the returned signal is from the position at which the instrument is pointed at and not from another object that is just off line but closer (or further away)?

1.3 Research Objectives

- Analyse the properties and specifications of various instruments and manufacturers to identify any differences between instruments.
- Verify that incorrect values can result from reflector-less measurements where the signal has varying reflective angles off a flat surface.
- Develop techniques that provide for more reliable use of reflector-less measurements, as well as recommend limits for the use of lasers where high accuracy results are expected.

2 Literature Review

2.1 Introduction

Like many professions, new technology is becoming more influential in many facets of surveying. Computer technology and CAD packages allow us to design, store and manage more and more data, while at the same time new technology allows us to collect data faster and mark-up points in the field with increasing speed and accuracy.

One such piece of equipment is the reflector-less (also known as prism-less) total station. Unlike conventional total stations or electronic theodelites, which require a prism to return the distance-measuring signal, the reflector-less signal, as its name suggests, does not require a prism but can simply reflect off almost anything. The main advantage of such reflector-less instruments is the ability to measure inaccessible points.

There could be any number of reasons that points are inaccessible, including safety concerns, such as forgoing the need to enter unsupported ground in underground mine surveying, detail surveys of busy road intersections where traffic control is undesirable or impossible, or simply finding locations of jetty piles where access simply isn't possible.

The problem arises then, of the accuracy that is given by such technological techniques. Whereas most survey measurements either are or at least can be checked for errors, reflector-less measurements, by their very nature of being inaccessible, are very hard to check. How then, can we rely upon such measurements, especially when high accuracy results are essential, and even simple checks like using a tape measure between two distinct points is impossible.

The aim of this project is to provide some guidelines outlining the accuracy and precision of reflector-less measurements in differing situations and to suggest some techniques to better ensure the accuracy of measurements made.

2.2 Background

Instrument manufacturers generally supply data sheets for their instruments as part of their marketing system, which discuss the key features and new innovations as well as specifications on performance and general information. While this information needs to be truthful, it can also be quite misleading. Obviously, while data such as size and weight are quite unambiguous, claims of accuracy can be misleading. For instance, the Trimble S6 Datasheet specifies that the reflector-less technology can "Measure quickly and safely without compromising accuracy" (Trimble Engineering and Construction Group, 2005). Immediately this raises questions about the ability of reflector-less technology to reflect the measurement signal solely off the point of interest. This can be challenging in difficult to access, crowded or confined areas.

So, while both theoretically and practically, the documented accuracies can be achieved, is it really that simple and reliable in the field? Would a reflector-less measurement signal reflecting off a wall at a perpendicular angle of incidence be more reliable? While the measured distance itself may be correct, is there a possibility that the signal width could cause questions about its reliability in certain situations? The Trimble S6 has a beam (DR signal) divergence of 20mm over 50m. Therefore, as shown in Figure 1, over a distance of one hundred metres, the signal from the corner is 40mm wide and 40mm high.

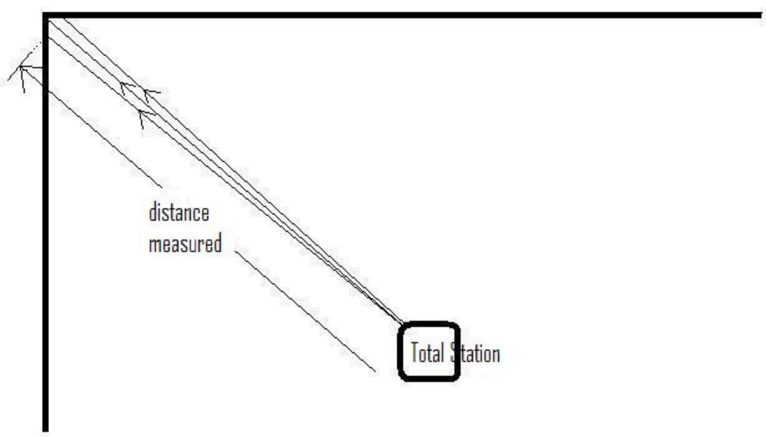


Figure 1: Reflector-less signal divergence at an internal corner.

This beam size is going to make it difficult to ascertain whether the distance has been taken to the corner itself or to the wall next to the corner. Conversely, using a normal prism shot to measure the distance, would ensure that the signal is reflected from the correct position.

Total stations are used to achieve high accuracy three dimensional coordinates that are calculated by the on board computer through the use of trigonometrical calculations. This is done by the instrument measuring horizontal and vertical angles as well as slope distance. Stored coordinates can then be used to calculate relationships between each point in the X,Y and Z planes. Clearly then, if a distance is measured incorrectly, then the resultant coordinate will also be wrong.

Another technology that is becoming more widespread are laser scanning instruments. They use the same reflector-less technology and read thousands of points at a very quick rate. Quoted close range accuracies of 9mm (Leica Geosystems) are common, with 30mm accuracy for greater distances and different instruments, and yet these instruments too, are likely to be afflicted with the same problems as reflector-less total stations. The difference is that as scanners are automated, a grid pattern of coordinates are recorded rather than user defined specific points. For this reason, the question of accuracy of a specific point does not apply, for as in the example above the corner is not specifically targeted.

2.2.1 Surveying Difficulties

There are a large number of examples of areas where reflector-less measurements are used at a distinct advantage. Underground mining uses reflector-less technology frequently, but generally the accuracy required is not high. In mining (and other earthworks) situations, a value with 0.05m accuracy would be sufficient. Mechanical surveys where new prefabricated steel structures need to bolt to existing steel structures can require accuracies to within millimetres only. There would be circumstances where even closer tolerances are needed, but these situations require specialist equipment and personnel and so won't be studied here.

Mineral bins are an example of infrastructure that are difficult to measure and therefore the accuracy of reflector-less measurements are questioned. They are generally large and high, and usually cylindrical. If there is no access to the top, measurements must be taken looking up and so there is doubt as to what the returned measurement has reflected off. This angle can be improved though, by moving further away from the bin to measured, if circumstances allow for this.

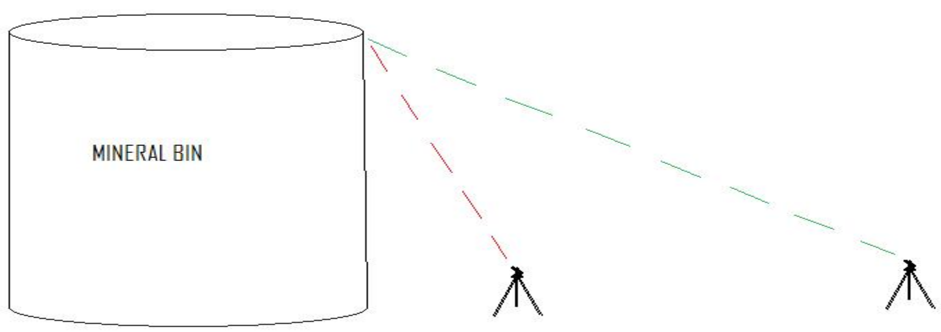


Figure 2: Mineral bin. Angle of incidence improved by distance form bin.

In the case of surveying large diameter pipelines (for instance, gas mainline 600mm diameter 22mm walls), accuracy sometimes needs to be within a couple of millimetres. Especially when bolt on flanges need to fit together correctly the first time, such as with expansions to major gas supply lines. In cases like this, the pipeline will be shut down for a minimal time only, and the expansion pieces need to bolt in without further welding or cutting. If using reflector-less measurements, there needs to be no doubt that the measurements are correct, even with a lot of clutter to measure around, and the fact that measurements will sometimes need to be taken to a curved surface and not at a perpendicular angle.

Traditional survey methods generally require access to any points that need to be measured. One exception would be to record a vertical and horizontal angle to a single point from at least two different positions. The coordinates could then be calculated. While this is possible, it would also be time consuming, especially if there were a large number of hard-to-see points. This need-to-access in the past, would have likely caused its own problems such as getting access to scaffolding or an Elevated Work Platform (EWP), but this access to points would also allow for measurements to be done using conventional means, as well as independent check for accuracy to be made.

2.2.2 Accuracy versus Precision

When used in general conversation, the words accurate and precise are generally interchangeable. In surveying however, accuracy and precision refer to separate results. Accuracy refers to the result's closeness to the true or accepted value. Precision refers to the spread of results for a number of measurements. For instance, six independent measurements of a line (using a single tape measure) could result in six different distances. These values may vary either by very little or by a lot. This is precision. If those results were close to the accepted value then they would also be accurate, but if the tape had been stretched, the results could be far from the accepted true value. Then, the given result could be said to have high precision but low accuracy.

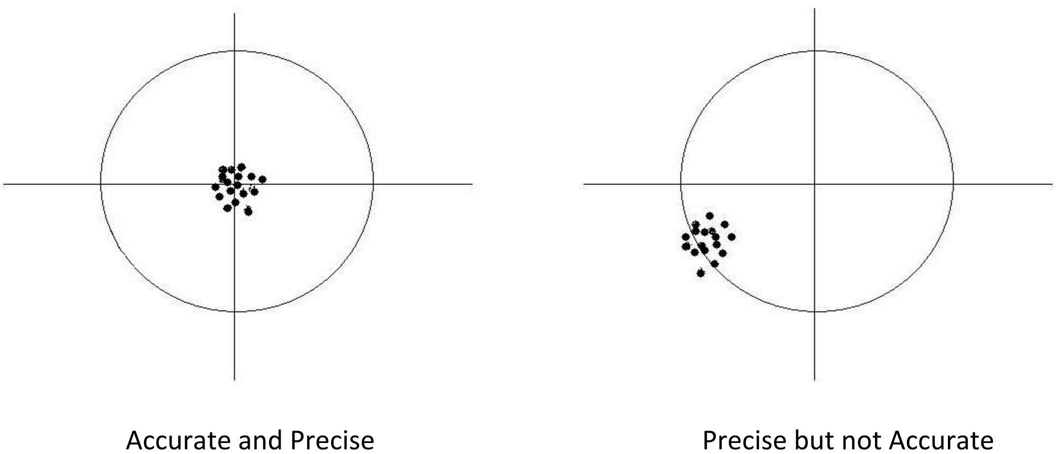


Figure 3: Accuracy versus Precision

As shown in Figure 3, many 'measurements' do not necessarily ensure a more accurate result. Therefore, repeated measurements from a reflector-less total station does not automatically increase the accuracy of the result.

2.2.3 Types of Errors

While survey observations can be highly accurate, observations are never exact, and therefore always contain some errors. (Wolf & Ghilani 2001). In surveying, there are three types of errors, known as systematic errors, random errors and gross errors (Dept of Civil and Environmental Engineering and Geodetic Science, 2001). Generally, they have different causes, and produce different results.

Gross errors are blunders, simple mistakes that should be found using checks during a survey. They can be caused by the surveyor, the chainman, the instrument settings and other variables. Often they occur through carelessness, an incorrect point being measured, hand recording errors and so on. Gross errors can be either big or small and are non-cumulative (Dept of Civil and Environmental Engineering and Geodetic Science 2001).

Systematic errors are a procedural error that can be mathematically modelled and therefore corrected (Dept of Civil and Environmental Engineering and Geodetic Science, 2001). For instance, measuring using Electronic Distance Measuring Equipment (EDM or EDME), with the incorrect prism constant will cause every point to have the same error, either toward or away from the instrument. Such errors can be remedied post survey through computer software and can be avoided using check measurements (to control points) and care when changing between prisms or types of measurements. Other systematic errors include level bubble out of adjustment on instrument or prism pole, level staff that has not been fully opened. Systematic errors can be either big or small and can be cumulative.

Random errors are the reason that measurements are never exact. They are small non-cumulative errors that occur as part of the measuring process. When reading a tape measure, deciding if the reading is 4.523m or 4.522m is a random error, as is instrument setups using optical plummets, pointing of total station to the centre of prism and the holding of prisms truly vertically. Random errors are difficult to minimise, since they cannot be stopped from occurring, we can overcome them using techniques such a minimising instrument setups or making a number of readings and taking the average.

2.2.4 Errors in Reflector-less Measurements

Reflector-less measurements, like all measurements, can have gross, systematic and random errors. Gross errors cannot be ignored, especially for reflector-less errors. Because reflector-less measurements by their very nature are likely to be inaccessible, it is often difficult to perform check measures. An example of this would be measuring the underside of a raised flange inside a shed.

Especially if the flange is close to the ceiling, we cannot be sure that the signal is off the flange or off the ceiling itself. If we had access to the flange, we could easily check the distance with a tape measure, to prove we have the correct distance. Without access, it could become a difficult task to prove.

Reflector-less instruments are no more prone to random errors than any other total station measurement, setup errors being an obvious one. This being the case, reflector-less measurements should have no more error than EDM measurements.

Normally systematic errors can be difficult to find if they occur. This is possibly exaggerated with reflector-less measurements as there is usually difficulty in getting a check measure. One problem with the reflector-less signal is that it may not be co-incidental to the observed target as indicated by the sighting crosshairs (Leica Geosystems). If this is the case, calculated positions from incorrect distance and angles could be incorrect in any direction depending upon how the object is measured. Theoretically, by averaging 'face left' and 'face right' observations, this error should be removed, but it would depend on what is being measured.

Another factor to consider is the size of signal. If measurements are taken from long distance, it is hard to ascertain where exactly the signal is being reflected from (Key & Lemmens, 2005).

2.3 Reflector-less Total Stations

2.3.1 Total Stations

A Total Station is an electronic surveying instrument that combines Electronic Distance Measuring Equipment (EDME) with an electronic theodelite and a computer. The electronic theodelite simply measures angle on two planes, the X-Y plane (horizontal plane) and from the X-Y plane (vertical plane). The EDME (or EDM) measures the distance (slope distance) to a prism to which it is pointed, while the on-board computer stores and calculates a large number of values form these three measurements.

EDM measurements are taken using laser (Light Amplification by Stimulated Emission of Radiation) technology, developed in the 1960s (Key & Lemmens, 2005). There are two types of measuring signals, 'phase shift' and 'time of flight' (TOF) also known as 'pulse'. Phase shift is considered the most accurate and has a narrow beam but has the disadvantage of a small range. TOF conversely, has a greater distance but a wider signal, resulting in a reduction of accuracy (Key & Lemmens, 2005). Only a small amount of energy is required to measure a distance to a prism using this technology.

As the name suggests, 'time of flight' measures the distance by directly converting the time taken for the laser signal to return to the instrument from the prism, while phase shift uses a set of different wavelengths to calculate the distance.

Using trigonometry, the computer uses the measurements to calculate horizontal distance, bearings, vertical distances, 3D coordinates, inverses (bearing / distance between points), real-time distance to a coordinate and a number of other values. Later total stations can also give cut / fill values to designs and calculate areas.

The electronic theodelite, which has evolved from the optical theodelite, uses two graduated plates to determine a horizontal angle and a vertical angle, usually from zenith. These values are output via a LCD screen. Bearings can be calculated simply by knowing the true instrument setup position as well as one other point which is used to set the bearing (backsite).

Before EDME became available, chains (long steel measuring band, usually 50m long) were used to measure distances which were both slow (calculations were required to adjust the distance for slope and for sag of the steel band) and required hand recording. EDME, along with digital data recorders allowed for vastly quicker and easier measurement, storage and revision of the data.

2.3.2 Reflector-less Measurements

Reflector-less measurements have only quite recently become in-built into total stations. They can allow for extremely easy safe and accurate measurements provided they are used correctly, and users are aware of their limitations. Range of these instruments have increased and some now exceed 1500 metres (Topcon Australia, 2009) to white targets or several hundred metres to natural darker targets. This is generally quite sufficient as at ranges of several hundred metres, it is difficult to accurately point the instrument at its target and beam divergence can become a problem.

In the mining industry, at times large ranges could be desirable to monitor pit walls but for the day-to-day workings it is not required.

Reflector-less EDMs requires a high-energy laser pulse (TOF method) to enable it to reflect off any surface it is aimed at. It is the high energy level of the laser that allows the detection of the reflected energy. This high energy output can cause a hazard (to eyesight) in some situations where there are pedestrians in close proximity or where the telescope is used and the surfaces are reflective or prisms are close-by (Leica Geosystems, 2005).

2.3.3 Reflector-less Measurement Uncertainties

There are two main causes of error and unreliability in the use of reflector-less total station measurements. These are caused either by beam divergence or reflector uncertainty. Reflector uncertainly is a situation when the laser beam is reflected off something other than what it was supposed to. This could be either in front or behind the desired object. This can only be avoided through care, checks on measurements, and instrument knowledge.

One of the main concerns with the accuracy of reflector-less total stations is beam divergence. As the size of the laser spot increases with distance from the instrument, so the accuracy of the measurement becomes less reliable. For instance, trying to measure a 50mm diameter pipe from 50m away would be difficult if the laser 'footprint' at this distance was 100mm diameter as is the signal from the Topcon GTP8205 (Leica Geosystems). It would not be reliable because there is no certainty that the signal reflected off the pipe itself rather than something in the background or even a combination of the two.

It is also noted that depending on the characteristics of the reflecting surface the "waveform of the laser beam scattered back by the surface may be a rather distorted version of the emitted pulse" (Key & Lemmens, 2005). This distortion can lead to uncertainties in the distance measured and can either give an erroneous result or no resultant distance.

Key & Lemmens (2005) also suggest that as the beam divergence increases, so too does the time range of the reflected signal off a certain plane. As shown in Figure 4, there is a difference in distance between the edges / centre of the laser beam, which can translate to a variation in the measured distance. Although, this would become negligible when the plane being reflected off becomes perpendicular to the laser beam.

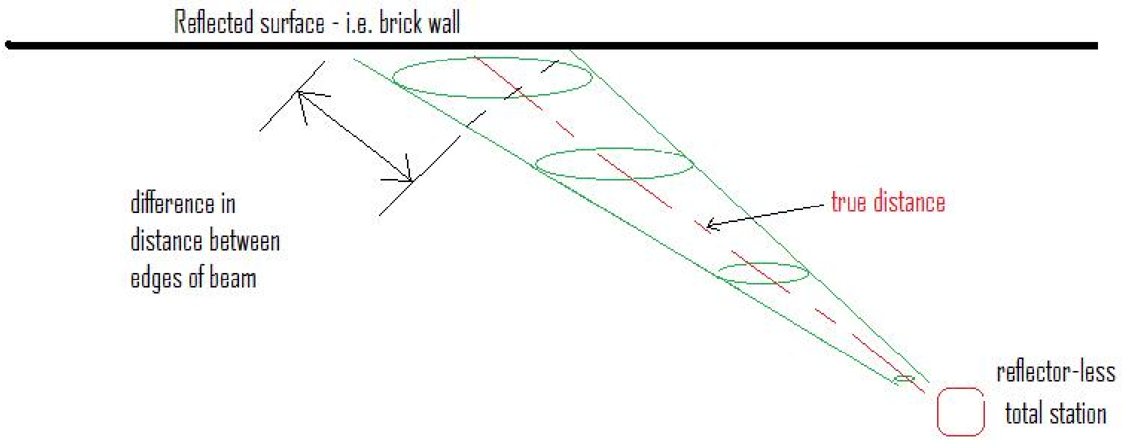


Figure 4: Laser beam divergence onto a sloped surface.

The greater the laser beam divergence, the larger the size of the laser 'dot' on the surface. As shown in Figure 4 above, there are two parts to the errors caused by laser beam divergence, the size of the 'dot' on the reflected surface and the angle of incidence with the surface. Unfortunately, by moving the instrument to a more distant position to lower the angle of incidence, also has the effect of increasing the size of the laser 'dot'. The ideal would be to setup the instrument at a perpendicular angle for each measurement. This would allow for a more reliable measurement but this is often either impossible or impracticable.

There a number of common total stations in Australia, which include Topcon, Trimble and Leica, each having their own specifications. When it comes to reflector-less specifications in the field, as long as the limitations are understood, errors should be avoided. According to Leica (Leica

Geosystems), the laser beam divergence varies greatly between instrument manufacturers, with the laser 'spot' varying in size from 9x28mm to 100x110mm at a distance of 50m from the instrument. Obviously, with such a variation, different instruments could be used in some applications while others would become unreliable.

2.4 Surveying Techniques

Although there is not a lot of data available indicating specific techniques for the use of reflector-less total stations, a Trimble Support Note (Haefeli-Lysnar, 2007) gives several techniques on the use of this technology in specific cases. Several of the techniques are based on calculations from indirect measurements. These include:

- The measuring of two intersecting wall planes to calculate the corner.
- Using the instrument's 'max range' and 'min range' to ensure there is no interference from other objects.
- Distance / angle offset by measuring a distance to centre of an object and using an offset to determine the edge position.

Non calculation-based methods include:

- Measuring in both face-left and face-right to "cancel out the effect of the slope caused by [an] oblique angle" (Haefeli-Lysnar, 2007)

2.5 Conclusion

Notably, there appears to be a significant lack of research completed into the reliability of reflector-less total stations in day-to-day surveying applications. While some information was found, the accessibility to these resources was limited. In most cases, abstracts were readily available but full papers were harder to come across.

Nevertheless, there is a good amount of data to support the quality of the instruments that are being manufactured, and it seems that some of the accuracy problems have not been quantified mainly because there are so many different situations in surveying. As field conditions alter, the quality of reflector-less results also changes.

Despite the fact that the instruments themselves may be as accurate as the manufacturers claim, it is how they are used that will ultimately ensure that the final results are within the surveyors stated tolerances. To this end, this research aims to offer practical recommendations for the use of reflector-less instruments in common surveying situations.

3 Methodology

3.1 Overview

To begin, two instruments will be used for the investigation, a Trimble S6 and a Trimble S8 which is a newer version of the S6, and only introduced late in 2007. While quite similar, both in appearance and use, the S8 has increased accuracy to a prism and while the reflector-less 'DR' mode has the same accuracy specifications, the beam divergence is smaller.

	Trimble S6	**Trimble S8**
Angular Accuracy	2"	1"
Distance Accuracy – prism	3mm + 2ppm	1mm + 1ppm
Distance Accuracy - reflector-less	3mm + 2ppm	3mm + 2ppm
Range Grey-card 18% reflective	>300m	>120m
Range Grey-card 90% reflective	>800m	>150
Divergence - horizontal *	40mm/100m	20mm/50m
Divergence - vertical *	80mm/100m	20mm/50m

* divergence stated are over different distances

Table 1: Trimble S6 versus Trimble S8 (Trimble)

Parts-per-million (ppm) is a measure of accuracy explaining that the expected accuracy is accurate to one millimetre per one million millimetres (any unit), so an accuracy of 2ppm is 2mm per 1000m. Hence at a distance of 100m, an accuracy of 2ppm calculates to 0.2mm and is therefore insignificant.

The study of the accuracy of reflector-less instruments will be broken down into several parts. Firstly, confirmation of the accuracy in the instruments' specifications needs to be established, both for the prism and reflector-less measurements. There then will be a number of tests carried out to determine how accurate the reflector-less instrument is in a number of situations.

A number of tests have been designed to simulate different field applications and should give a good indication as to how reflector-less results vary. These include:

- Measurements to a perpendicular plate; to check accuracy of reflector-less instrument.
- Measurements with a varying 'Angle of Incidence'; to see what difference is generated by measurements to a non-perpendicular target.
- Direct measurements to an external corner; to establish what accuracy results.
- Direct measurement to an internal corner; establish from where the signal is reflected from.
- Measurements to a curved surface, to determine how accurately a laser can measure to it; similar to measuring with a varying 'angle of incidence'.
- Measurements to different materials to prove that reflector-less measurements are accurate to various common materials.
- A check of long distance measurements to verify the stated accuracy over a range of distances.

- Experiment with the effect of angle of incidence when measuring up a tall object.
- To establish the size of the reflector-less signal, measure to a bolt head from varying distances to ascertain what distance will allow for accurate measurements to a small target.

Many of the 'true' measurements were taken using the same instruments as the tests conducted to establish the reflector-less accuracy. While the S8 has better accuracy specifications than the S6 using a prism, and so was used as the 'true' value, even the 3mm + 2ppm that is achievable with the S6 (and used to check the distance established by the S8) the aim of this study is to establish errors with the reflector-less technology. As instrument measurements of this type are only accurate to several millimetres due to both the instrument and setting up (random) errors, small errors of up to three millimetres will be ignored in most cases.

Forced centring was used where possible to eliminate the errors caused through the use of optical plummets. When forced centring wasn't able to be used, such as in the case where a number of setups was used to establish true coordinates, resections were used to reduce the effects of centring error.

Effects of atmospheric corrections, although entered into the instruments for PPM (parts-per-million) corrections, will have no effect if the measurements are all taken at the same time. This is because the instrument corrections will be the same for both prism measurements and reflector-less measurements. Both instruments though, need to be set to the same correction.

3.2 Perpendicular Accuracy

Before starting various tests on accuracy, it must be proved that the results from a simple, perpendicular measurement gives the accuracy that is stated in the instruments specifications. From this model we can show any divergence from the instrument accuracy specifications.

Simply, a distance was measured using a prism to a white target, and then again using the reflector-less signal. This was then be repeated a number of times in increasing distance sizes between 10m and 100m. The object was a painted concrete tilt-panel building and a number of measurements were taken to it at an angle of incidence of approximately zero. A distance was then read several times to check for deviation, both using reflector-less EDM and using the flat 2mm prism. The distance was measured from four different distances, that have a close proximity as longer distances would not be used to gather accurate measurements. The distances from instrument to wall are 11.3m, 40.5m, 79.2m and 103.6m.

3.3 Confirmation of Beam Divergence

The intention of this trial was to establish by field observation to what distance a small size object could be measured to before the beam divergence began to give inaccurate results. In this case, due to its resemblance to field operations, a bolt head was measured to. By starting at a close range, and progressively moving further away, a range threshold could be established for accurate measurements to small targets.

The true distance was first established by measuring the computed horizontal distance to a flat prism placed on the wall behind the bolt head and subtracting the distance that the bolt head protruded from the wall that was measured using a steel rule. This is done for each instrument setup as the distance is increased between instrument and target. Then, using reflector-less measurement mode, the distance was measured to the bolt head itself. In this way, once the reflector-less measured distance does not match the 'true' distance subtract the bolt protrusion distance, we can affirm that the 'measurement beam' divergence has negatively affected the accuracy and reliability of the reflector-less measurements.

The first trial was a failure because even from a distance of just ten metres, the 'bolt head', that needed to be covered to eliminate a hole, did not measure correct distance; that should be the distance to the wall subtract the protrusion distance. This is possibly due to the fact that the hollow 'bolt head' was covered using black electrical tape. After this failure which was done to a 'bolt head' with a ten millimetre diameter, the methodology was replicated using two created bolt heads of different sizes. For all of these beam divergence trials, the instrument has been placed at right angles to the object. With this approximate zero angle of incidence, any errors associated with non normal measurements have been eliminated.

Figure 5: Targets of the beam divergence trial.

The two bolt heads were chosen randomly, to represent a range of real world problems. The first had a diameter of twelve millimetres, and the second had a diameter of twenty two millimetres. Both the bolt heads, and the background were painted white, to ensure neither the target (bolt head) nor the surrounding background had any reflective advantage. The protrusion distance was measured from the backing plate to know when the distance was being accurately measured to the bolt head and not to the backing plate. The measured distance should be the distance to the backing plate with the protrusion distance subtracted. In the case of the twelve millimetre bolt head, the protrusion distance was thirty two millimetres from both the backing plate and the separate white target. The twenty two millimetre bolt head had a projection distance of twenty nine millimetres.

Logically, in relation to beam divergence, as distance to the object increases, so too will the beam divergence. Hence as the measurement beam width increases, an increasing amount of the returned signal will be from the background and not from the target, in this case a bolt head. For each sized bolt head, the instrument (Trimble S6) was started at an arbitrary distance from the object and moved closer incrementally to determine at what distance from the target the correct measurement was made.

3.4 'Angle of Incidence' Measurements

The 'angle of incidence' measurements were probably the most important, as these results replicate closely what is a common surveying measurement. The reflector-less measurement of an object from a position that is not at right angles to the surface of the object. There is going to be several possible errors caused in these situations. Firstly, the alignment of the measurement signal with the optical alignment would make the measurement signal reflect off a point that is not the same as the point that is lined up using the eyepiece. Secondly, and a problem that would increase the error as distance increases, is the size of the measuring signal and the effects of beam divergence.

This trial was carried out using both the Trimble S8 and the Trimble S6 instruments in a private car park area, against an extended brick walled building. Firstly, ink marks were made on the wall at approximately five metre intervals that were then measured accurately using the 1mm flat prism. This was done from a distance of 21 metres, and from a point midway along the wall so as to negate any effects of errors caused by angle of incidence. As a check for the control data, these points were also measured using the S8 reflector-less mode. A second control point was also established closer to the wall from which the angle of incidence trial measurements would take place. This second control point was placed just eight metres from the wall.

Using forced centring to exclude optical plummet errors, the instrument was setup on the newly established control point from where the reflector-less measurements were taken. Measurements were taken using both 'face-left' and 'face-right' configurations to determine any differences caused by alignment with both instruments.

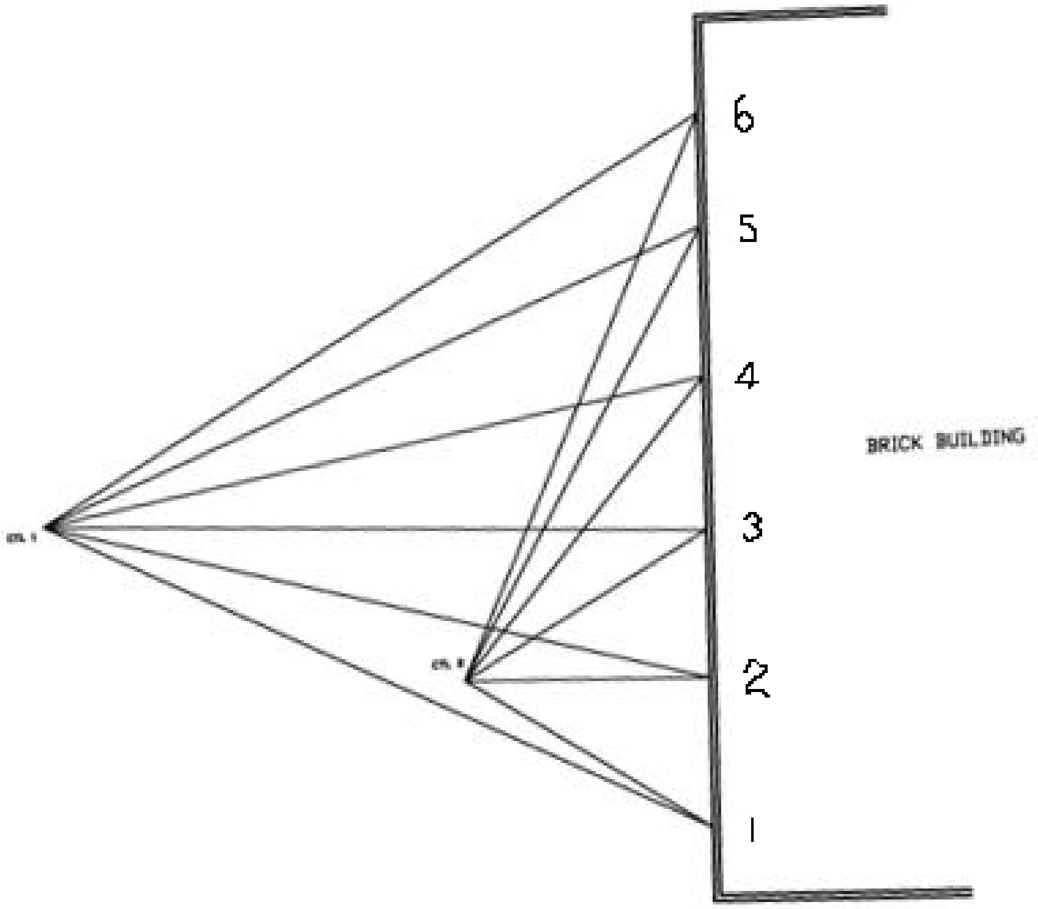


Figure 6: Plan view, Angle of Incidence Trial

As a check, a separate instrument setup was completed to take prismatic measurements parallel along the wall (at a parallel offset of 88mm) to ensure the distances measured from the first instrument setup were correct in the east – west orientation (see Figure 6 above).

A technique (Haefeli-Lysnar, 2007) to be proved is the use of 'face left / face right' averaging. This assumes that the distance measured to an object at an angle of incidence will cancel out any errors using two faces. This could be correct if the reflector-less signal is not coincidental to the line-of-sight as per the instrument crosshairs, but if the error is due to the width of the measurement signal, it may not make any difference.

There was need to redo some of these measurements again mainly due to the large 'angle of incidence' increments but also to corroborate the results. As such, a new site was chosen, both to try and increase the distance between instrument and wall and to use a different surface as the reflected material. A smooth concrete tilt panel building was used for this second angle of incidence trial.

The main differences between the first and second 'angle of incidence' trials is the distance between the instrument and the wall, the wall material (smooth concrete as opposed to clay brick), and more measurements, ensuring a smaller variance between successive angular measurements. This was intended to more clearly show where the reliability and accuracy begins to erode.

Measurements were taken using both 'face-left' and 'face-right' with both the Trimble S8 and S6 instruments to examine if there are any differences caused by measurements on both faces. The aim of this is to effectively establish whether there are any errors brought about by the non-coincidence of the optical crosshairs and the reflector-less 'beam'.

The targets were marked on the wall at approximately equal distances of roughly three metres apart and the instrument was setup in an arbitrary position 18.8 metres from the wall. A backsight angle was taken and recorded to ensure nothing had moved throughout the trial and checked once all the measurements had been taken, and also to allow (using forced centring) the setup of both instruments in the same position and orientation. This allowed for the simple comparison of results.

With these dimensions, the second 'angle of incidence' trial has a variety of different angles, both to the left and right of square (angle of incidence of zero). These angles can be seen in the table below.

Angle of Incidence **<u>decimal degrees</u>**
-47.4
-38.6
-27.4
0.5
9.1
16.7
23.5
27.2
37.6
41.9
45.8
49.1
52.1
54.7

Table 2: Variance of 'Angle of Incidence' measurements.

The table below shows a range of measurements with an angular range of 102^{o}. This ranges from 47^{o} right of square to 55^{o} left of square. This seemed to be an adequate range considering the results of the first trial.

3.5 Measurements to an External and Internal Corners

An 'external corner' is a corner that is viewed with the walls running away from the observer. An 'internal corner' is one that is viewed with the walls running toward the observer (Figure 7).

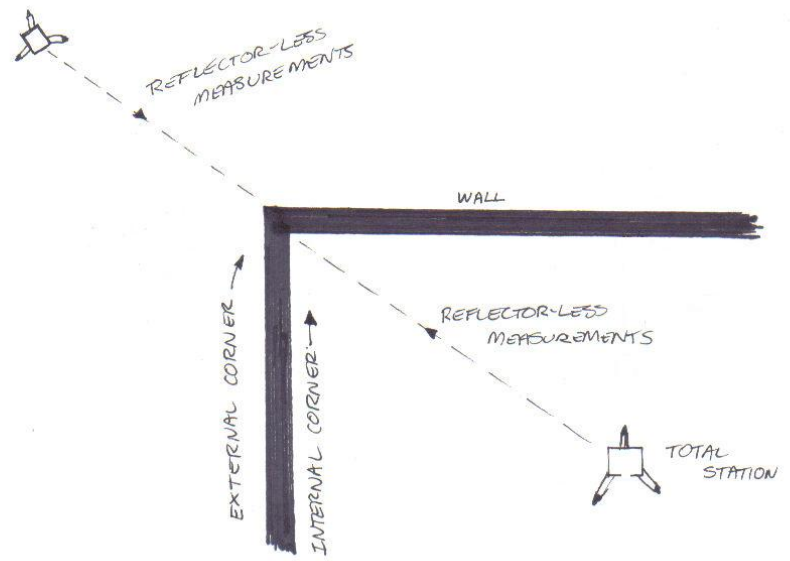


Figure 7: Measuring to Internal and External Corners

The problem with measuring to corners is the 'beam' (signal) width and divergence. As the distance from the instrument increases, so does the beam width, which at corners can cause a range of distances returned to the instrument from one measurement. With the S8, at a distance of 50m, the (claimed) 20mm divergence would give a distance range due to beam divergence of approximately 14mm. However with the S6, if shooting to a horizontal corner, as in a corner found between ceiling and wall, the 40mm divergence at 50m would equate to a range in received distances of approximately 28mm.

Like the measurements to an external corner, internal corners cause much the same problem but instead of measuring long as per the external corner, measurements range from accurate to shorter than the true distance. See Figure 8: Beam Divergence at an external corner.

According to Haefeli-Lysnar (2007) one technique in surveying corners is to get two wall shots for each wall that intersect to create a corner and use those lines to generate a corner point. While this is a viable survey technique, it can just as easily be carried out post-survey using a computer package. It also assumes that each wall is straight and that the angle of incidence that is needed to get each measurement has no significant errors. [This is explained fully later in the study]. To this end, the trial was carried out to see how the corners affect the accuracy of the measurement as the distance increases from the corner.

The effect of increasing distance between object and instrument is caused by beam divergence; as the distance from the corner increases, the beam width increases and it follows that the distance between the shortest and longest signals returned to the instrument also increases. This is shown on the diagram below (Figure 8).

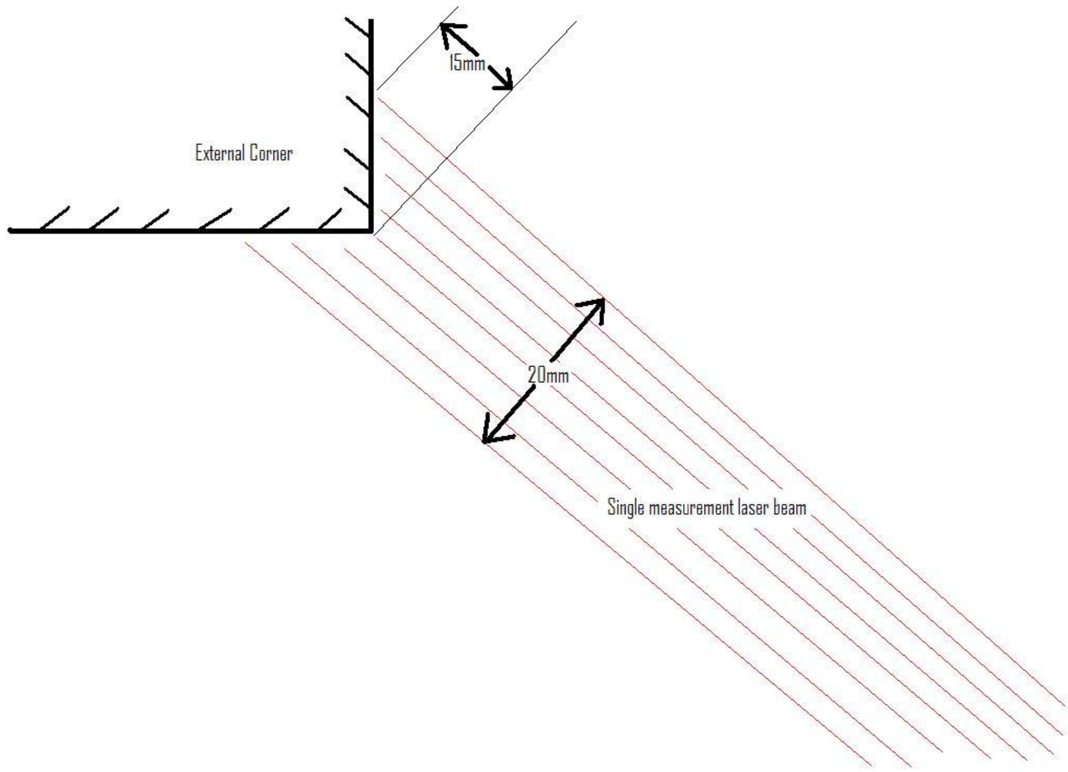


Figure 8: Beam Divergence at an external corner.

Distances to an internal corner are similar, as the distance between instrument and corner increases, so too does the distance between the longest and shortest returned signals for each measurement. Obviously, with a wider signal, as distance between instrument and object increases so too does the distance increase between the centre of the measurement signal and the edges. Assuming the centre of the measuring signal is at the point of the corner, any width of that signal must be closer to the instrument which obviously means that those parts of the signal will return quicker and give a reading that is closer than it truly is.

The measuring of external and internal corners was done on tilt panel building corners, with the internal corner being silicon sealed and therefore not having a sharply defined corner. The external corner however was concrete and a well defined corner.

To test the corner measuring abilities, which relate to beam divergence and width, a number of measurements were taken at increasing distances from the corners. The corner was measured accurately first using a flat prism which had been stuck to the corner of the wall. Then, from the same position, the reflector-less measurement was taken with the same instrument, at a point two hundred millimetres below the prism. The wall had been previously checked for verticality and only horizontal distance measurements were logged.

One problem encountered at the beginning was where the reflector-less observation was reflecting off the prism, even though it did not seem to be even close to the optically aimed instrument. This happened where the internal corner was 'behind' the prism set up for the external corner. In fact, the prism was approximately 250mm offline to the reflector-less target. This was a problem even when the instrument was set up only ten metres away. Simple to solve, the prism was removed and the measurements redone.

The measurements were taken at a range of distances from the corners, approximately every ten metres but randomly positioned. The distances were; 10.3m, 23.0m, 32.6m, 40.6m, 50.1m, 59.3m, 67.2m, 78.9m and 88.9m. Although the distances didn't approach the maximum range of the S6 instrument, distance inaccuracies had already become discernible through the field booking. Additionally, if accurate measurements are being pursued, then the distance should be kept to a minimum.

3.6 Measurements to a Curved Surface

Curved surfaces can cause accuracy problems when measuring distances using reflector-less technology. This is due to the difficulty of determining where the signal 'point' is being reflected from and whether that point is the same point as is sighted through the crosshairs of the eyepiece. This error is similar to the 'angle of incidence' error that is effected by measuring to a point on a surface that is not perpendicular to the measurement signal.

A trial to test the accuracy in these cases was carried out on a galvanised steel water tank with a radius of 5.2 metres. Survey points were marked around the tank at intervals of approximately one metre. The survey marks were then accurately coordinated using a +1mm prism constant flat prism (reflector). To negate the effect of accurately measuring to a prism at a high angle of incidence, two setups were used in this process, both resections and at differing angles to so that measurements to the prisms on the tank were at a larger angle of incidence. In this way, each measurement was taken at an angle that is close to perpendicular to the tanks surface. One point on the tank was measured twice, once from each setup as a check to ensure both the quality of control setup, and of the measurements with the flat prism.

Figure 9: Trimble S6, with resection control point and galvanised steel tank in background.

Control was established using two arbitrarily placed tripods (with circular prism) that remained in place for the entire trial. These points were coordinated at the beginning, and were then used as resection base stations for the other setups. Each of the other setup points, including the setups to establish the true coordinated points were done in this way. Resections have the advantage of eliminating optical plummet error, so that each setup point is as closely related to each other point as possible. The Trimble S6 instrument used in this trial calculates error ellipses for its position with the use of redundant measurements. In each case the error ellipse was at most one millimetre.

Figure 10: Curved surface with author in background about to take reflector-less measurement.

Four setup points were used for this trial, with an increasing distance between tank and instrument from 10m, 16m, 30m and 44m. These distances are from instrument setup point to closest part of the tank. Clearly, the distances between instrument and tank changed even within a single instrument setup due to the radius of the tank. This difference, of up to four metres, has been taken as inconsequential due to both its small magnitude as well as the range of distances measured using a range of setup positions.

A number of setups were used both to gather a large dataset of information with a good range of 'angle of incidence' values and to determine whether increased distance from the reflected surface was to make a difference.

3.7 Measuring to Different Materials

This was simply a trial to prove whether different surfaces cause any errors in the distances measured using reflector-less technology. These results were simply a collation of results from various other trials, where measurements were taken to different materials, from angles that were close to perpendicular between measuring signal and object. Materials included brick, galvanised steel and concrete.

The aim here is to look at structural materials only as (in general terms), the roughness of stone and other natural materials, even if they are used for construction, would preclude sub-centimetre accuracy.

While the results of this collation focuses upon measurements taken at right angles to the object's surface, it doesn't take into account any differences that are caused by a combination of different materials and angles that are not at ninety degrees to the object's surface. The reason only measurements with low angles of incidence are used is that this ensures there are no other factors involved that will affect the results. There is a possibility therefore, that different surfaces will give varying results depending upon what angle the measuring signal strikes the object's surface.

3.8 Measuring a Vertical Surface

The final trial's aim was to check the effect of measuring to a tall object. One of the greatest uses of reflector-less instruments is the ability to measure to objects that are inaccessible. Quite often this is due to objects being at a height where a ladder is too short, or are not able to be used for safety reasons.

This was a simple test to attempt to confirm any the results of the 'Angle of Incidence' test. The difficulty was in finding an accessible wall with a ladder that was high enough to conduct the experiment. Obviously, access was needed onto the object to get accurate prism measurements with which to compare the reflector-less measurements.

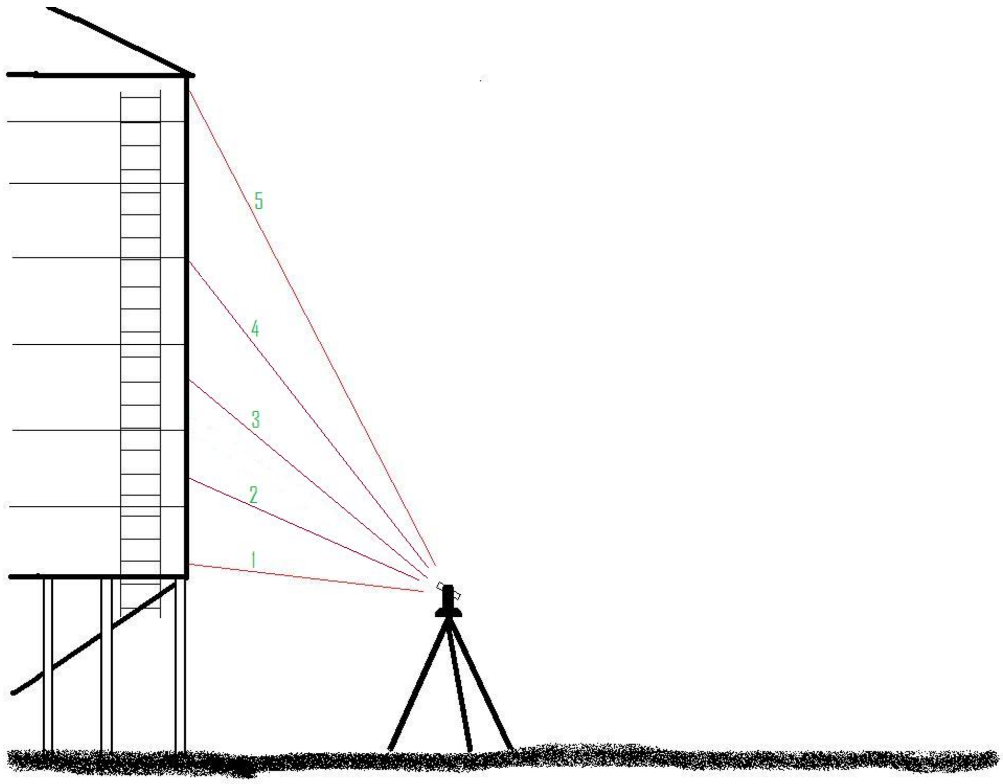


Figure 11: Measurements to grain silo.

Because the silo was of only limited height (about 5 metres), to get a varied 'angle of incidence' range, only one setup was made, quite close to the silo. Such a close setup could affect the results of this trial for two reasons.

i. At close distances the signal measuring 'dot' is quite small, as the slope distance is small and the signal itself diverges with increasing distance from the instrument. Therefore, if these results were to be interpreted over a greater distance, the result may not agree with an actual trial.
ii. Any error in coincidence between the line viewed through the crosshairs and the path of the measuring signal will be minimal in terms of X, Y,Z. Again, if there was any errors in signal coincidence with crosshairs, it wouldn't be distinguishable over such small distances. So, if the same experiment was done on a greater scale the results could be different.

Even so, at such a small scale, it is important to be able to validate the results of other experiments done in this study. It should be remembered however, that due to the instrument beam divergence as stated in the specifications, these results should have a greater degree of error than the horizontal trials, for the S6 at least. According to the instrument specifications, the S8 has a smaller more regular shaped signal.

According to the instrument specifications, a Trimble S6 has a measuring signal 'dot' of 80mm/100m (Haefeli-Lysnar, 2007). Therefore, beam divergence increases by 4mm (to a flat surface) from the size of the original 'dot' at the maximum distance measured of 4.9 metres. So at the top of the silo the beam ‘dot’ has a vertical footprint of 11 millimetres, made up of 4mm original beam size, 4mm divergence, and 3mm due to the angle of incidence.

To ensure each of the four points on the silo were accurately measured to provide control, the marked points were measured using a flat (1mm prism constant) prism. As a check, to confirm the distance between marked points, a tape measure was hung from the top and each point was measured off. The verticality of the silo was checked as vertical using a builder’s spirit level as the breeze made plumbing inaccurate.

Once the points had been accurately coordinated using the flat prism, each point was measured again using the reflector-less signal using the ‘stake-out’ program which allows for easy processing of the resultant coordinate as compared to the first accurate coordinate.

The ‘stake-out’ program on the S6 / S8 controllers are used primary for the staking out of points in the field but can also be used as a compliance tool for Quality Assurance. The known ‘correct’ point (point measured using the flat prism in this case) can be selected and staked-out. When the instrument has been optically aimed the measurement with reflector-less can be taken and immediately a set of differences will be displayed on the controller screen. This will include ΔEast, ΔNorth, ΔRL, ΔHorizontal Angle, ΔVertical Angle, ΔHorizontal Distance as well as others. In the processing stage, it is then a simple matter to get a report from the software (Trimble Geomatics Office). Most error data can then be read directly.

4 Results

4.1 Results Overview

The results below refer to actual measurements taken for the purpose of this research project.

For the sake of having an acceptable result versus an unacceptable error, 4mm will be the cut-off for acceptable errors. This is because for both instruments the specifications note that the direct reflex (reflector-less) measurement error is three millimetres plus two parts-per-million.

4.2 Results of Perpendicular Accuracy

The following table shows the difference in the EDM distances measured using the Trimble S6 between the prismatic and reflector-less options on the total station. While not a great number of observations were taken, they were important to check that the instrument's stated accuracies were as good as the instrument specifications.

Distance (m)	*11.3*		*40.5*		*79.2*		*103.6*	
Instrument	**S6**	**S8**	**S6**	**S8**	**S6**	**S8**	**S6**	**S8**
	1	0	1	1	0	1	1	1
	1	1	0	0	0	0	2	1
error (mm)	2	0	0	0	1	1	0	1
	0	1	1	0	2	1	1	0
	1	1	0	1	1	0	1	1
Mean	**1**	**0.6**	**0.4**	**0.4**	**0.8**	**0.6**	**1**	**0.8**
Std. Dev.	0.6	0.5	0.5	0.5	0.7	0.5	0.6	0.4

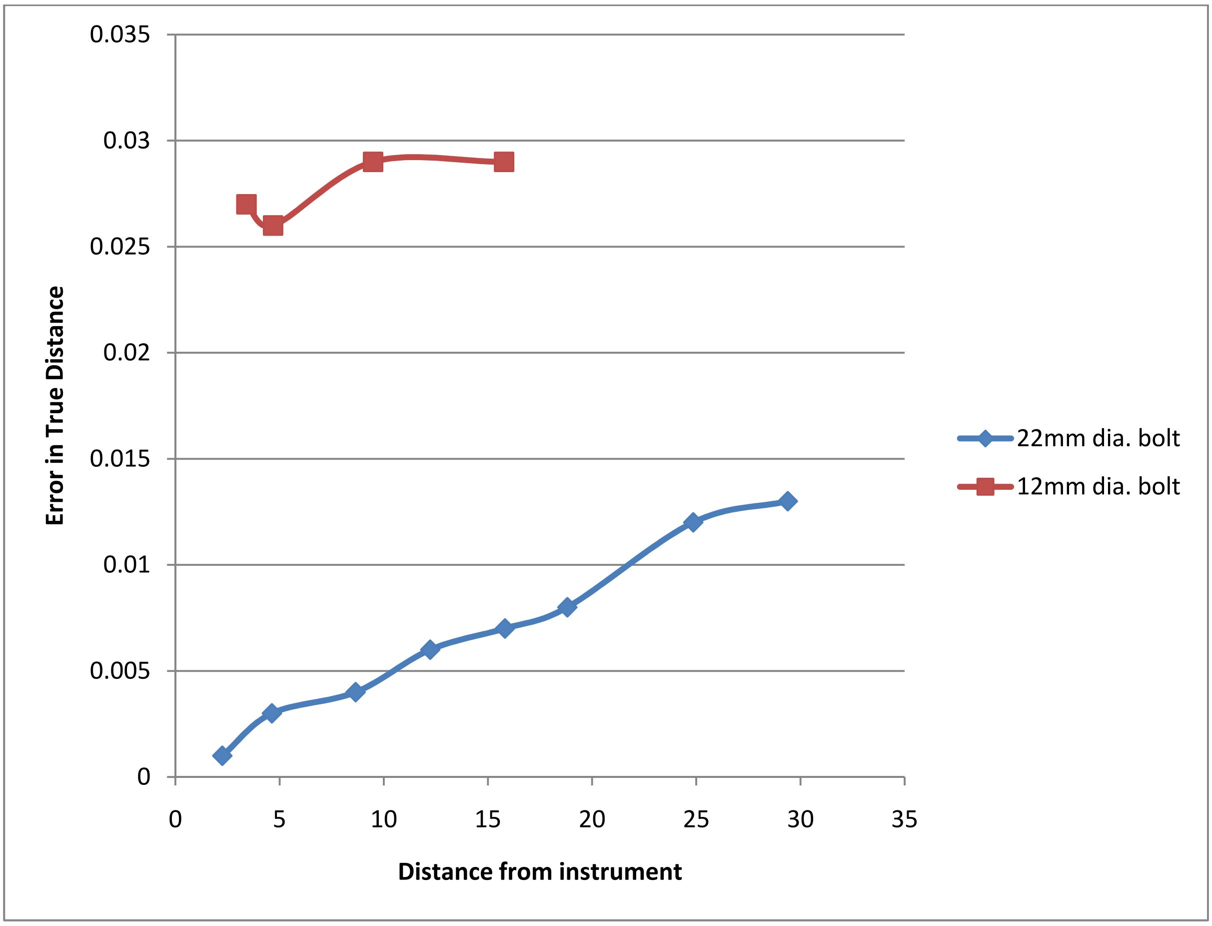
Table 3: Trimble S6 / S8 perpendicular accuracies.

There is a small range between successive measurements but are at most only two millimetres and all the measurements lie within the manufacturers specifications. This shows that each instrument's reflector-less signal can measure to the specifications where the object being measured to is flat, of reasonable size to reflect the signal and is at a generally square angle to the measurement signal.

4.3 Results of Confirmation of Beam Divergence

The idea behind this trial was to determine if reasonably small objects can be measured to reliably using reflector-less technology. Measuring to bolt heads is a real world application and to know what distances can be measured to reliably, could be a practical solution for hard to access positions.

Surprisingly these results show that small objects are difficult for the instrument to read to accurately, as Graph 1 shows. The bolt head with the twelve millimetre diameter could not be measured to with a high degree of accuracy. Starting at fifteen metres away, and progressively moving closer, the distance was measured first to the plate (white painted) directly above the bolt head and compared to the distance measured to the bolt head itself.



Graph 1: Beam Divergence shown as error over distance from instrument.

Measurements were taken at ever smaller distances until the instrument was too close to read a distance. The bolt projected past the plate by thirty millimetres so the data suggests that at less than ten metres from the target, the bolt head has a little influence on the distance measured, but essentially a twelve millimetre target is too small to return the signal and such measurements are unreliable. My first trial that was thought to be a failure actually verifies this hypothesis.

The measurements to the twenty two millimetre bolt head clearly show the relationship between the instrument - target distance and the error in the measurement to that target (bolt head). While the distance wasn't long enough to find the vicinity where the protruding bolt fails to affect the measured distance, it clearly shows that for a circular target with a 22mm diameter, having an instrument – target distance of more than eight metres will introduce errors of greater than the four millimetre tolerance.

Obviously larger targets will allow for greater distances of accurate measurements. Further work is required to model acceptable accuracies for a range of targets over a range of distances. It is also possible that different materials will make a difference to these results, such as was found in the measurements to galvanised steel (page 42).

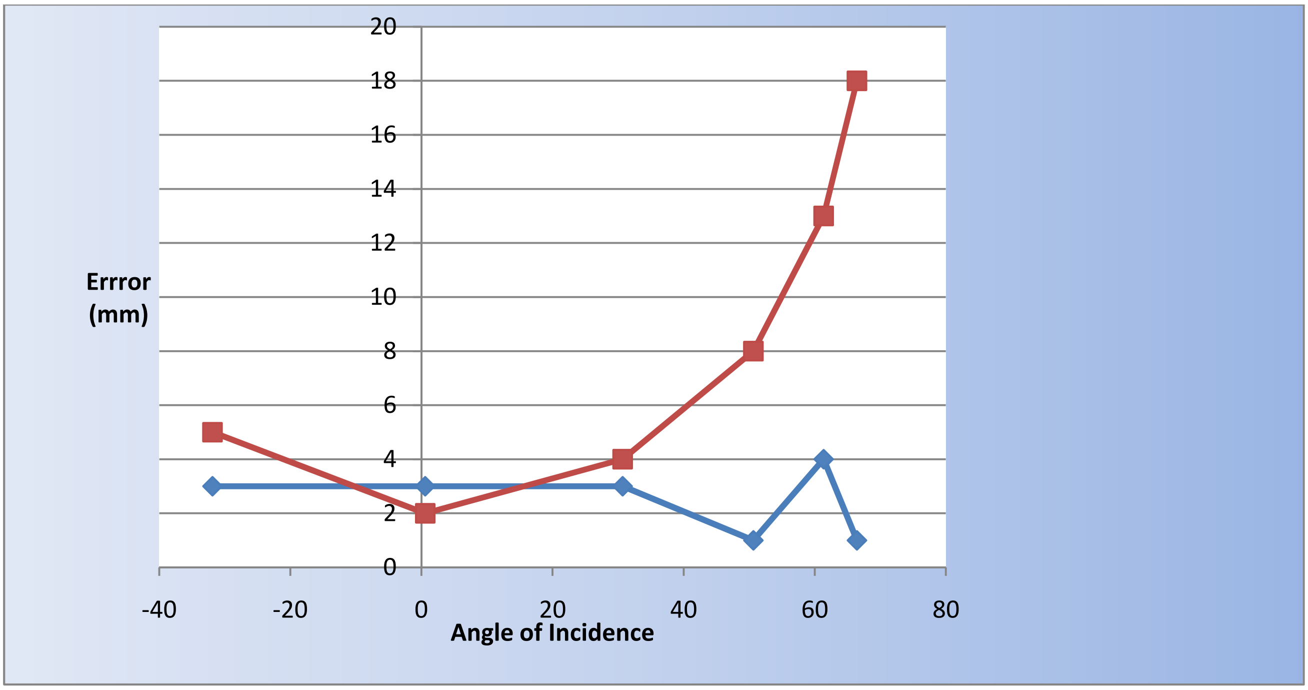
4.4 Results of Angle of Incidence Measurements

Two separate trials were conducted for the angle of incidence trials, due mainly the minimalistic range between the angle of incidence measurements on the first trial. The two trials used different sites, different distances between instrument and object and different materials of the object. While the distances were different, both were quite close, and this was done to lower any errors that are due to beam divergence which is expected to grow rapidly as distance increases.

One error that could influence the results of this trial is the fact that as the angle of incidence increases, so does the distance from the instrument. Unfortunately, this is quite a difficult problem to deal with, the only solution being to keep moving the instrument closer to the wall as the angle of incidence increases. This potentially introduces additional which result form a large number of instrument setups.

The graph below (Graph 2) shows the error increasing rapidly as the angle of incidence increases when using the Trimble S6, while the error remains within tolerance using the Trimble S8. This graph suggests that the S6 has acceptable measurement capabilities when the angle of incidence is less than 30 degrees from square. It also suggests that the S8 instrument is much more reliable when measuring to objects that have a greater angle of incidence. Indeed, the error remains within the four millimetre tolerance even as the angle of incidence approaches seventy degrees.

Due to the building size, only one measurement was taken to the right of square and while this gives an indication that the resultant errors would mirror the left side (i.e. the right side of the graph). It would have been helpful however to be able to get more measurements to the right of square.



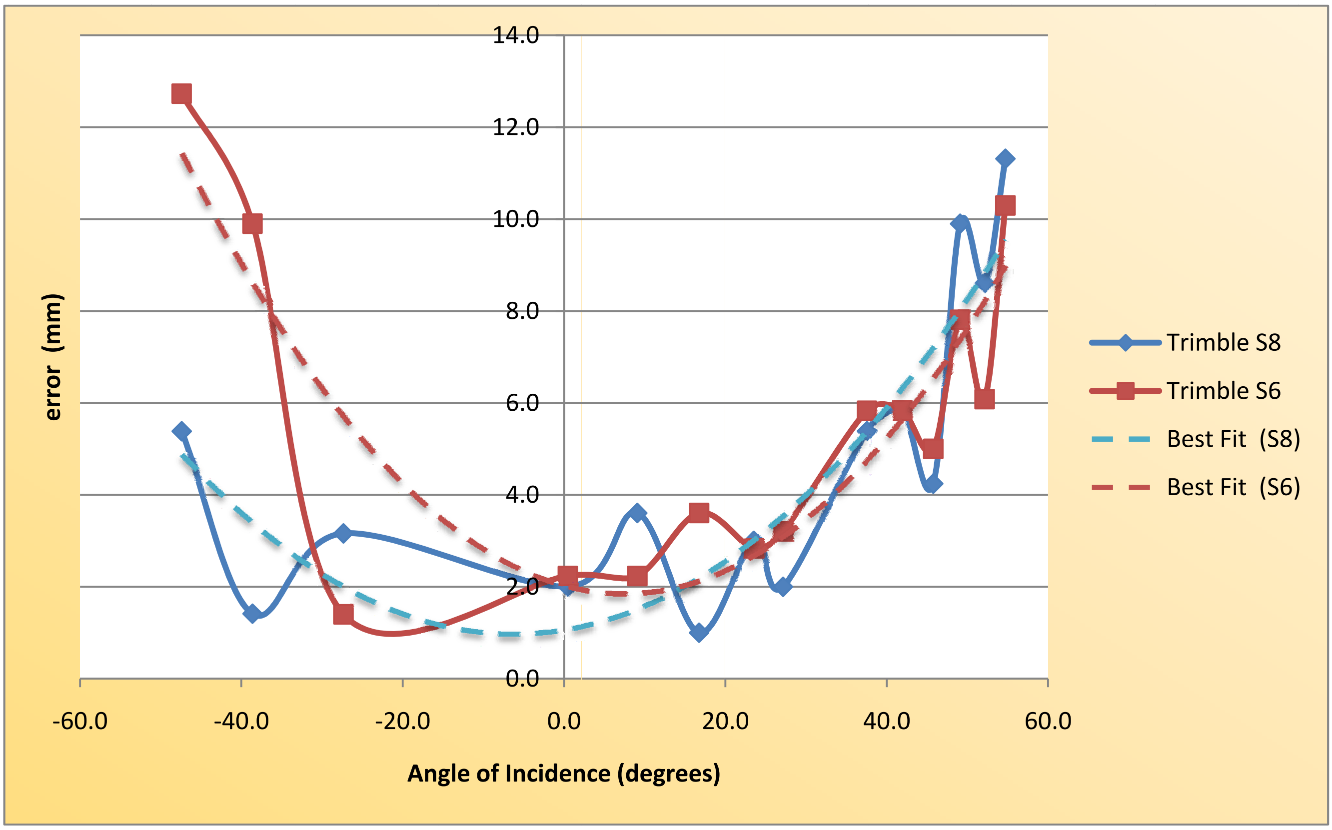
Graph 2: Results from trial 1 'Angle of Incidence'

The second ‘angle of incidence’ graph (Graph 3) shows the results of trial 2 which was conducted on a separate site as explained in the methodology. A greater range of measurements were taken for this trial but results were expected to be similar to the results o the first trial. That is; within the four millimetre tolerance up to approximately thirty degrees from the normal using the S6 and within tolerance results of above sixty degrees with the S8.

Interestingly, the second trial had different results. As can be seen on the graph, the accuracy (within tolerance) for the S6 instrument remains similar to the first trial. For measurements both left and right of the normal, accuracy is within tolerance while the angle of incidence remains below approximately thirty degrees. This is shown with both the direct readings and made more clear by the dashed line-of best-fit.

The S8 however, has results that while closely matching the results of the S6 in this trial, were at variance with the results from the first trial. According to the line-of-best-fit as indicated by the dashed blue line, the four millimetre tolerance is exceeded when the angle of incidence increases above approximately forty degrees to the right of normal (that is, negative or the left-hand side of the graph), and approximately thirty degrees to the left of normal (that is, positive or the right-hand side of the graph).

The other feature to note on the second trial results, and shown by the graph, is the unevenness of the magnitude of error as the angle of incidence increases. Especially that both the S6 and the S8 results show similar ‘porpoise-ing’ shapes. The reason for this is unknown, however it doesn’t seem to affect the graph as a whole.



Graph 3: Results from trial 2 'Angle of Incidence'

The two trials are good in that the second one corroborates the results found in the first, especially in regards to the S6. Even though there are differences in the S8 results, they do clearly show that as angle of incidence increases, so the reliability of reflector-less measurements decreases rapidly.

The fact that the two trial results for the S8 do not match each other well, may reflect that other factors such as object material could also play a part in the reliability of the measurements.

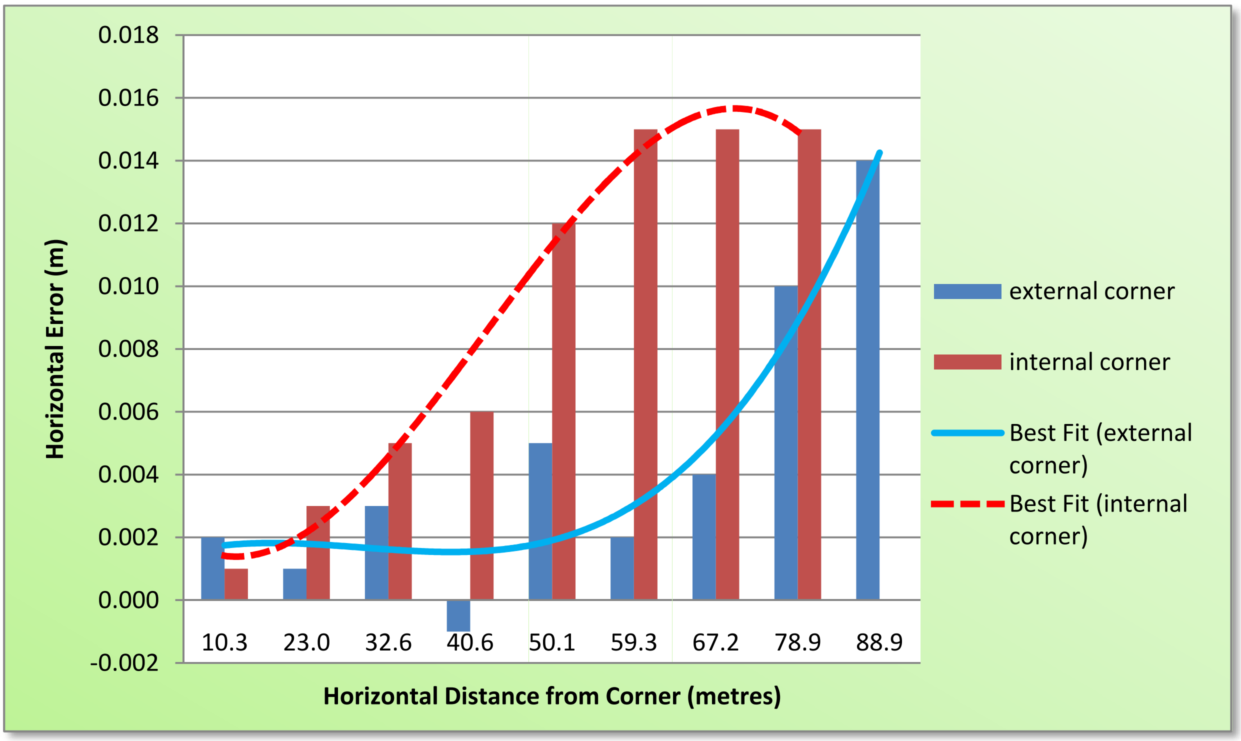
4.5 Results of Measurements to Internal and External Corners

Perhaps unsurprisingly, the results for the internal and external corners were different to each other. Although there is a pair of outlier in the results, generally they point to a fairly regular change in the accuracy. The intricate details on how the instrument's reflector-less technology works is beyond the scope of this research but the data seems to suggest that the first received part of the reflected signal has much weighting in the final distance recorded by the instrument.

While the graph below (Graph 4) doesn't show it, the internal corner always measured short while the external corner always measured long. There is a single exception to this which was measured from a distance of 40.6m and measured the external corner short by one millimetre. As this error lies well within the acceptable tolerances for the Trimble S6 reflector-less (as well as the S6 prismatic expected error) it has been simply accepted as a negligible error by the instrument.

The graph illustrates clearly that for internal corners, the accuracy drops off quickly as distance from the instrument increases. From a distance beyond about thirty metres, the measured internal corner becomes unreliable. This is shown by both the line of best fit and the error component of each of the measurements.

The internal corner error in the measured distance seems to flatten off when the distance is sixty metres from the instrument. While this may indicate a cessation to the growth of error, it is unlikely due to the reasons for this error as outlined below. And, at an error of fifteen millimetres, any reliability of accuracy for these measures would ensure such measurements would be disregarded. As once the error has exceeded the four millimetre accuracy tolerance any return to the within tolerance will then be an unreliable measurement.



Graph 4: Errors to internal and external corners

The external corner measurements stayed within the four millimetre tolerance until the instrument-corner distance reached almost seventy metres. There was an outlier from this data set at the distance of fifty metres. In this instance, the error was five millimetres and since the next two more distant observations were within tolerance (error values of three and four millimetres for sixty and sixty seven metres respectively) this value has been accepted as a measurement anomaly which do happen, and also due to the fact that it is only one millimetre out of tolerance. It is for this reason that critical measurements must be independently checked.

While this trial does not conclusively prove that corners measured using reflector-less technology (with the Trimble S6) are inaccurate from distances greater than thirty metres for internal corners and sixty metres for external corners, it does suggest this. One of the greater issues is that all instrument makes and models are more than likely to have different results to this type of testing. Given that new (and 'improved') models are entering the market every year, specific instrument trials will always become out of date within several years.

The reason that the corner measurements were inaccurate was beam divergence. The internal corner measures short and the external long because of first part of the signal returning to the instrument is from where the distance is calculated. Obviously, on an external corner, the point of the corner is the closest to the instrument and will therefore reflect the signal first. As the increases its distance from the corner, the bulk of the returned signal becomes at a greater and greater distance from the corner point due to divergence; so that the error starts to be introduced to that measurement. The same theory can be applied to the internal corner except that as the distance between the instrument and corner increases the divergence produces measurements that are not from the corner itself but from the adjoining walls....

4.6 Results of Measurements to a Curved Surface

As was expected, measurements taken with an angle of incidence of almost zero degrees were more accurate than those measurements that had a high angle of incidence. Obviously, a better reflected signal will be returned from a perpendicular surface.

Interestingly, the resulting reflector-less coordinates achieved an accuracy that is not on par with the instrument's specifications of 3mm+2ppm for measurements taken at an almost perpendicular angle. As stated earlier, even though over these distances of less than one hundred metres, the 2ppm is negligible the tolerance has been accepted as four millimetres because 3mm + 2ppm is greater than 3mm, although only marginally so. As can be seen on the table below, especially at the closer instrument points, this accuracy of plus or minus three millimetres has not been achieved. The reasons for this are outlined below.

The setup at instrument 'Stn30' also has an anomaly, where an error of thirteen millimetres has been measured to Point T8 at an angle of incidence of only 3°30'. This error does not fit the rest of the data and has therefore been largely ignored. It does however corroborate an existing survey adage, saying that there must be independent survey checks to prove survey data is correct. Whether this measurement was incorrectly aligned, or just an unexplained irregularity, is unimportant; the importance being that even though an instrument may be shown to have certain specifications, there are always errors, and therefore measurements must always be confirmed.

The blanks on the table below (Table 4) show targeted positions that were;

- either not seen from the instrument setup due to the curvature of the tank, or
- had attempted measurements made to them but no reading could be taken.

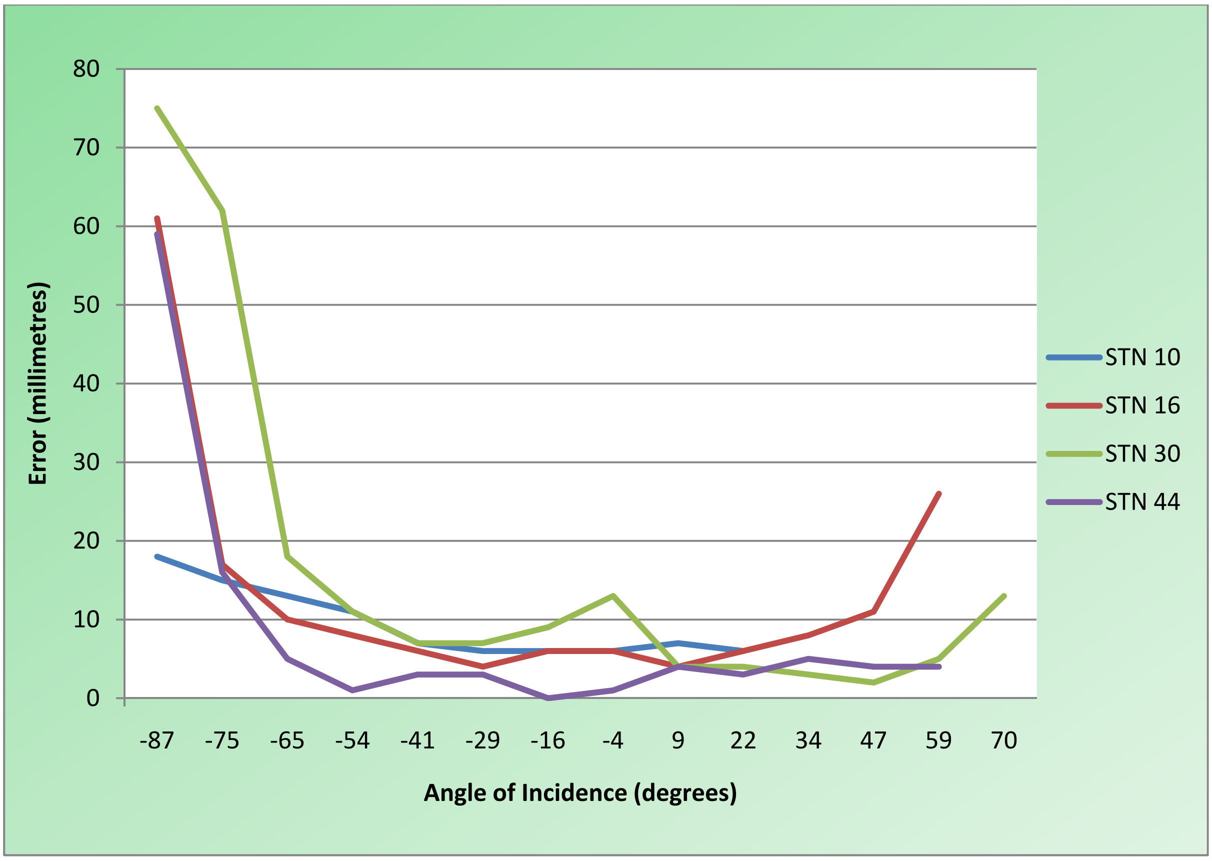
point on tank	STN 10 angle of incidence	error (mm)	STN 16 angle of incidence	error (mm)	STN 30 angle of incidence	error (mm)	STN 44 angle of incidence	error (mm)
T1					-87.45	75		
T2			-77.32	61	-74.65	62	-74.82	59
T3			-67.6	17	-65.15	18	-65.48	16
T4			-55.55	10	-53.65	11	-54.27	5
T5	-68.85	18	-42.38	8	-41.38	7	-42.4	1
T6	-55.75	15	-28.68	6	-28.92	7	-30.45	3
T7	-41.52	13	-14.58	4	-16.32	9	-18.45	3
T8	-26.05	11	-0.17	6	-3.52	13	-6.28	0
T9	-9.76	7	14.23	6	9.27	4	5.88	1
T10	6.83	6	28.32	4	21.95	4	17.48	4
T11	23.15	6	41.93	6	34.48	3	30.00	3
T12	38.72	6	54.97	8	46.77	2	41.92	5
T13	53.13	7	67.28	11	58.67	5	53.57	4
T14	66.5	6	79.05	26	70.3	13	65.03	4

Table 4 ; TANK; Angle of Incidence versus Error

Generally, as the angle of incidence of the signal increased, so did the difference between the true value for each survey point. As can be seen from both the table (Table 4) and the corresponding graph (Graph 5), when the angle of incidence is closer to perpendicular, or within approximately 30 degrees of the angle of incidence the resulting measurement is reasonably accurate, although not necessarily within the instrument specifications.

Strangely, the closer the instrument was to the tank, the greater the error for each point, especially when the angle of incidence was small. For instance, at a distance of ten metres, measuring at a angle of incidence close to zero (ten degrees and seven degrees) gave errors of seven and six millimetres respectively. At greater distances, similar angles of incidence have errors of between four and zero millimetres. The reason for this is the nature of the object. Galvanised steel, being so shiny is highly reflective to an instrument that can measure reflector-less distances of several hundred metres. The problem of too much returned signal is the reason for this error. This is corroborated by the data which has more accurate readings as the distance between the object and instrument increases.

Also noted on the data is that the error is much greater for 'negative' angle of incidence measurements. On the table and graph, negative angle of incidence measurements are simply those taken to the left side of the instrument to the tank (from the instrument's perspective).



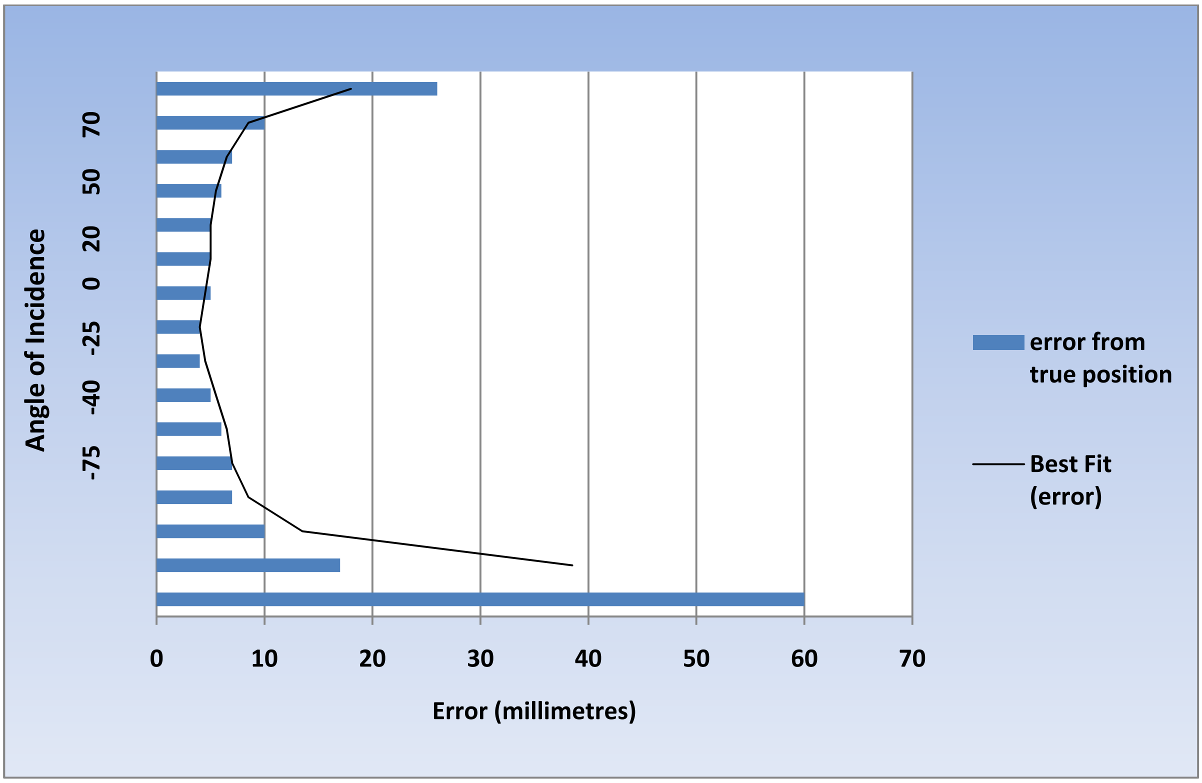
Graph 5 : TANK; Angle of Incidence versus error.

The above graph (Graph 5) clearly shows the range where results become more accurate. Of the fifty measurements taken to the tank, nineteen had an angle of incidence less than thirty degrees (from the normal). Of those fifty measurements only fifteen were within the four millimetre accuracy specification and only nine of those were part of the group that had an angle of incidence of less than thirty degrees.

This suggests that the galvanised surface may cause a problem with the reflected signal. Other possible causes could be atmospheric (although these settings were checked and recorded on site) or instrument accuracy over close ranges.

Although face-left and face-right measurements were taken to each position, there was little difference observed between each corresponding FL/FR observation. This ranged up to three millimetres and generally occurred in the measurements with higher angle of incidence and error. For this reason, the face-right data was not studied any deeper. Also, due to the way this trial was carried out, a lot of extra manual analysis would be required.

One part of the data set that was difficult to represent, either by table or graph was the direction of error. This was easily seen using AutoCAD (drafting program) but required zooming into a plan view of the whole trial. Noticeable however, was the general trend, with only a few outliers, that on the left side the measurements were too long, on right side they were too short and all were towards the centre of the tank. Although this indicates a problem with the coincidence of the reflector-less signal and the optical alignment, this is an unlikely cause due to the checking of face-left / face-right observations.



Graph 6 : TANK; average angle of incidence versus error.

Graph 6 gives an overall indication of the averaged error as compared to the angle of incidence from the data shown in Table 4 ; TANK; Angle of Incidence versus ErrorTable 4. While it clearly indicates that the error reduces significantly as the angle of incidence approaches zero, it also shows that for this trial the specified accuracy of the Trimble S6 has not been met.

As stated above, while the results strongly indicate that the angle of incidence does influence the accuracy of reflector-less measurements of the Trimble S6, the results aren't conclusive due to the fact that the range in errors between different instrument setups and angles is quite large.

There could be some error in the coincidence of the sighting cross-hairs and the laser signal, and although this could cause errors, it is unlikely in this case due to the lack of data clustering and at such small distances, any error would be minimal. It must be noted that the instrument has been checked for laser mis-alignment and no error was found.

As stated earlier, post field trial investigation suggest that highly reflective surfaces such as polished steel returns too much data for the instrument to accurately compute. This possibly could have been overcome by measuring these close distances using the normal EDM. This means a weaker signal is transmitted therefore less data is returned to the instrument. This has not been tested.

4.7 Results of Measuring to Different Materials

Different materials have differing reflective properties and although these measurements were taken at differing times and places, there seems to be some question regarding the dependability of measurements taken to some materials. This study looks only briefly at differing materials and more as a result of choosing correctly shaped objects for other trials than as a specific test. Therefore these results are a collation of different trials at different times and are used as a guide only.

Measurements for this study were taken to concrete, galvanised steel and clay brick. Different distances were used for each measurement and all at different times. However, as the table below (Table 5) indicates, at closer distances, there seems to be problems receiving accurate results when measuring to galvanised steel surfaces.

DISTANCE	galvanized steel	brick	concrete
10	6mm too far	0mm	
16	6mm too far		
19			1mm too far
30	4mm too far		
44	0mm		

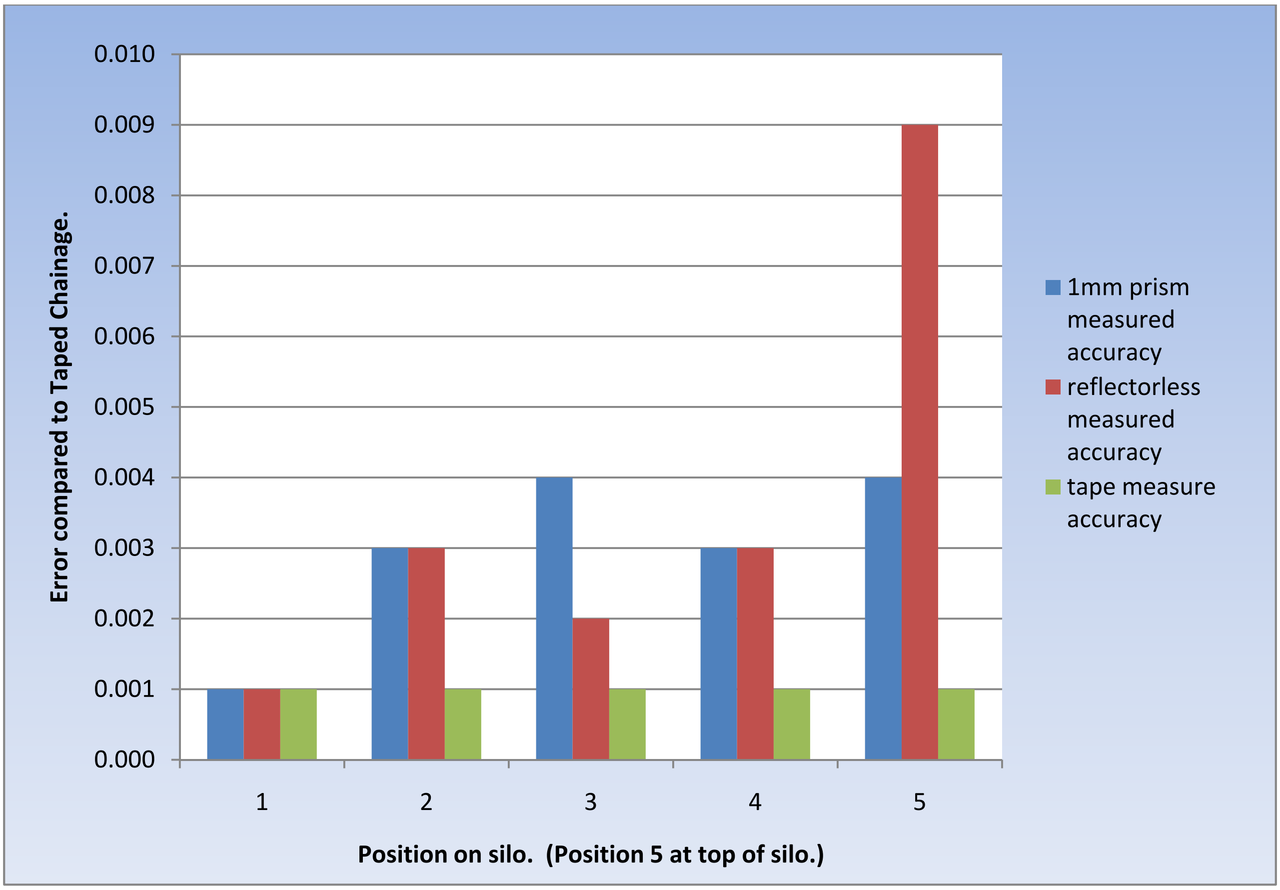
Table 5: Errors involved in different materials

Interestingly, with several independent measurements to the same point from different instrument setups onto the galvanised steel tank, it is unlikely that there is a survey blunder or a measurement anomaly. It could be suggested therefore that at very close distances (of under fifty metres) very reflective surfaces give unreliable results. The reasons for this is that too much data is being returned to the instrument as discussed in section 4.6.

4.8 Results of Measuring to a Vertical Surface

While the results of this trial will have only limited value due to limitations on the size of the vertical wall, it was necessary to give at least an indication of the accuracy of the Trimble S6 on vertical surfaces, and more specifically, accuracy with vertical angles of incidence.

Each marked point on the silo was measured using a calibrated tape measure, and it was this data that was assumed as correct, as for such an operation, a steel tape will gave the best results, and most easily checked. As an independent check, the flat 1mm prism was used to measure each point, although it must be noted that difficultly of aligning the cross on the prism with the marked cross on the silo whilst hanging off a ladder could probably cause a small amount of error.



Graph 7 : Errors when measuring to a vertical surface.

The graph indicates that the reliability of reflector-less measurements decreases dramatically as the angle of incidence increases. As can be seen in the graph, the accuracy of the tape measured values has been accepted as +/-1mm. The flat prism gives results with an accuracy of up to 4mm that while lying outside the expected instrument specifications accuracy of 3mm is not unexpected due mainly to the difficulty of aiming the telescope at such angles. Unless a right-angled eyepiece is used, it becomes physically challenging to look through and point the telescope without disturbing the instrument. This affects both the sighting for the reflector-less and prismatic measurements, as the targets were aligned optically for both measurements so as to negate any possible effects caused by laser-pointer misalignment.

Position	Horizontal Distance	Vertical Distance	Slope Distance	Angle of Incidence	Reflector-less Error (mm)
1	3.66	0.050	3.66	0˚47'	1
2	3.66	0.750	3.74	11˚34'	3
3	3.66	1.275	3.88	19˚12'	2
4	3.66	2.062	4.20	29˚30'	3
5	3.66	3.289	4.92	41˚56'	9

Table 6: Silo measurement's 'Angle of Incidence'.

The table above (Table 6) shows the associated 'angles of incidence' with each of errors shown in the above graph (Graph 7). Silo positions (as per Figure 11) one to four all have acceptable errors (within the instrument specifications) but position five with an angle of incidence of almost forty two degrees has a large error. While the small data set makes any conclusions unreliable, it can be used to support other findings.

5 Discussion of Results

5.1 Discussion Synopsis

It is important to note that this study was done in the anticipation of finding some well defined results for the limits of reflector-less reliability. While the results (Chapter 4) certainly give some strong indications of these, there remains a number of questions in regards to specific variables. These include the measurements to galvanised steel and in conjunction with this, how other highly reflective surface respond to reflector-less signals.

There are a great number of variables in this study which have not been fully investigated due to time constraints. These include the use of other instruments, both different instruments of the same models, and different makes and models. Other variables include doing similar trials on two similar objects but differing materials and using increased distances for each trial, especially the vertical surface.

5.2 Results

As outlined in the individual results in Chapter 5, several overall conclusions have been formed through the process of carrying out these trials. As stated previously these studies have been carried out solely on the Trimble S6 and S8 and are therefore pertinent to these instruments only. However, as reflector-less measurements technology is quite similar between all total station instruments, it is likely that these conclusions can also be applied to other instruments as a generality.

1. As the angle of incidence of the measurement signal increases, so too does the error. Once the angle of incidence reaches thirty degrees from the normal, any measurement loses it's reliability and is unlikely to fall within the manufacturers specifications.
2. Measurements directly to corners become more unreliable with increasing distance. External corners can be reliably measured from up to sixty metres away while internal corners are reliable up to only thirty metres.
3. Measurements taken to very reflective surfaces (such as polished metal surfaces) can affect the reliability of the resultant measurement, especially if close to the object (less than thirty metres).

5.3 Accuracy and Reliability

Reliability and accuracy, although different, are looked at together in this study. It is assumed that once the loss of accuracy (as a trend) has increased to greater than the instrument's specified error, then measurement reliability is lost. If we take the results from the data and apply it to declare that accuracy is lost once the angle of incidence reaches thirty degrees from the normal, then reliability will cut-off at the same point. Simply, if we did the same trials but wished to keep the reliably of all our measurements within an accuracy of four millimetres, we would stop trying to measure to objects where the angle of incidence is greater than thirty degrees. Similarly, when measuring to external corners our range would be within sixty metres of that corner. For internal corners we would not extend our distance to more than thirty metres. Likewise, for other day-to-day fieldwork where low tolerances to accuracy are expected, these same rules would apply. .

5.4 Precision

In the context of this study, precision refers to the repeatability of measurements. For each trial, face left / face right measurements were used mainly to cancel out any errors involved in the angular measurements of the instruments'. This also had the advantage of checking that results had a good degree of precision in relation to distance measurement. There is no evidence from this study to suggest there is any lack of instrument precision.

Precision is shown in the four separate trials using different materials, object shapes, positions and distances angle of incidence resulted in approximately the same result. Both 'angle of incidence' trials as well as the field trial to the vertical surface resulted in conclusions that the cut-off for measured distance, with an accuracy within the instruments' specification, was at approximately thirty degrees. That is to say, once the angle between the instrument and the object's surface increases to greater than thirty degrees from the normal, reliability becomes uncertain. The tank trial, which essentially was the same trial done by a different method on different material, showed corroborating if not similar data. While harder to interpret due to issues with erroneous data, the tank trial indicates that measurements up to forty degrees from the normal could be within instrument accuracy tolerances.

5.5 Possible Surveying Techniques when Reflector-less is Not Adequate

It is important to be aware, as always in the surveying industry, that errors are associated with all EDM measurements and reflector-less measurements can be even more prone to these errors due to a lack of understanding of their limitations.

As the above results show, there are occasions when reliably accurate results are required and can not be obtained by reflector-less observations. This could be due to a number of reasons including high 'angle of incidence' of the measurement signal, inconclusive confirmation that the measuring signal is being reflected off the desired object or non-corroboration between consecutive measurements. Whether 'reflector-less' is found lacking through check measurements or through the inspection of the survey site, other techniques need to be used, as there should always be a solution to meet the client's needs. Whether or not the solution is acceptable to the client (especially by cost / time) is a different matter, at least unreliable data is not being gathered and utilised.

Where access is possible to the object being surveyed, it is generally simply a matter of using one of a various range of prisms to get an accurate measurement. At times, the distance and the angle may be different but total station software will allow for this, either by measuring the distance and then swinging onto the correct horizontal and vertical angles before recording the measurement or by inputting offsets into the instrument, angular or distance offsets.

Clearly more difficult is when the object to be surveyed is not accessible to be able to use a prism. In these situations, if reflector-less is not able to be used even by changing the position of the instrument, the most likely option left is to record the angles only, form two (or more) different instrument setups. Much like a resection in reverse, and most likely post-processed on a computer, using two sets of angles will allow the calculation of an accurate coordinate. In these cases, a third set of angles would be used as a check.

Other options could be available depending upon the circumstances of the job as well as the specifics of the equipment being used and the accuracy of results that are being pursued. Such things as setting up and reading at right angles off a baseline can also be options.

In the end though, as long as an accurate, reliable measurement is recorded, the technique for getting that result does not matter.

5.6 Ongoing Equipment Trials

Technology has been moving forward at a very rapid rate in the past few decades, in all parts of life including the science of measurement. As new innovations are created, the quality of reflector-less measurements will also improve, until they become as accurate and reliable as measurements using prisms, and perhaps even better as there can be no errors involved with the positioning of the prism in the correct place.

As new and 'better' equipment becomes available, there will be a need to provide proof of how accurate and reliable this newer technology really is. Using this study as a starting point, trials could be carried out to show how well the newer total stations can measure to objects that proved the Trimble S6 unreliable in certain situations. For instance, equipment that has a smaller measurement 'beam' and no beam divergence should be able to get better results from a longer distance to measurements to a corner.

Other trials using the same total station (Trimble S6 and S8) could also be done to look more widely into the accuracy and reliability of reflector-less measurements. This could involve a more comprehensive trial into the reflector-less accuracy of differing materials. While this study briefly examined the differing effects of material reflectiveness and instrument accuracy, there are a large number of materials that could be required to be accurately surveyed using reflector-less technology. Stainless steel, mild steel, galvanised steel, aluminium, chromed surfaces and, as well as a vast range of non-metallic surfaces; dressed timber, painted surfaces, polished stone, concrete, brick and plastics. This short list is by no means exhaustive, but merely aims to give an indication of the extensive number of different materials that could require surveys upon.

Once any object material factors have been removed from the dataset, a better understanding of lack of accuracy caused by angle of incidence changes could be achieved. This would simply be a matter of associating an error factor to different materials (through field tests) before doing field trials of angles of incidence to either structures or a built template that rotates of a tripod.

5.7 Different Equipment

While the results from this research indicate that for the Trimble S6 and S8 instruments, angles of incidence greater than thirty degrees begin to introduce accuracy reliability problems to reflector-less observations it does not necessarily stand true for other types and builds of total stations. Other instruments have differing specifications such as different reflector-less beam divergence and may therefore get better (or worse) results when measuring to a certain object with differing angles of incidence. It is therefore important that when using other total station equipment, that the results of this study are used as a general guide only.

Figure 12: Trimble S8 Total Station (Trimble, 2007)

While there are a large number of total station makes, there seems to be four main brands used in Australia. These are Leica, Sokkia, Topcon and Trimble. There are also a number of other total stations on the market including Nikon, South, GeoKing and CST/berger. Almost all of these instruments have reflector-less capabilities but whether their accuracies are the same in different situations is unknown. The ability to compare a large number of these instruments should give a good indication as to whether the issues raised by this research in regards to measurements with angles of incidence greater than thirty degrees would go a long way in determining whether this problem is due to the technology or the instrument.

6 Conclusion

While this study neither encompasses all situations that could be found in the surveying industry, nor studies a wide variety of instruments, it strongly indicates that the accuracy, reliability and precision is not necessarily as good as the instrument specifications suggest. In certain situations, it must be realised that such tolerances may not be met. Assuming that all measurements recorded using reflector-less technology are correct may lead to errors in the dimension of structures and the incorrect prefabrication of new adjacent structures.

The results of this study have accomplished two of its major objectives. It has confirmed that while measurements at right angles to an object are generally well within manufacturers specifications, measurements to surfaces that are not at right angles to the measurement beam can introduce errors. Moreover, where the angle of incidence is less than thirty degrees from the normal, results tend to be within instrument tolerances (Trimble S6 and S8 at least). As the angle of incidence increases past thirty degrees the error increases rapidly.

A number of techniques have been discussed that provide options for when access isn't possible and reflector-less measurements are deemed unreliable. A set of instrument limitations has also been found for various situations including limits for direct measurements to internal and external corners (maximum distance of 60m for external corners and 30m for internal corners), and indications of the limitations when measuring to small targets such as bolts amongst steelwork. Also noted is the measurement errors that can be created by measuring to highly reflective surfaces from close proximity.

Unfortunately, the third objective of this study was only partly met, no other manufacturer's instruments were able to be included in this study due to resource limitations, and so only the two Trimble instruments were compared. Although there were some small differences in the results, overall conclusions remain the same.

While more study, mostly of other instruments, would be ideal to allow for the widespread use of reflector-less total station limitations (as outlined above), the results set out in this study do strongly indicate what these limitations are. Of most importance though, is for all users of such equipment to realize that just because the instrument can take a distance reading, it does not necessarily mean that it is correct. Where low accuracy tolerances are paramount, the use of non-reflector measurements must be checked. As always, the surveyor needs to be able to prove that any measurements taken are true and of appropriate accuracy for the job at hand.

7 Bibliography

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111 / 4112 Research Project

Project Specification

FOR: Leigh Herbert COAKER

TOPIC: AN INVESTIGATION INTO THE ACCURACY, PRECISION AND RELIABILITY OF PRISM-LESS TOTAL STATIONS.

SUPERVISOR: Dr Albert Chong

PROJECT AIM: To investigate the accuracy, precision and reliability of prism-less Total Stations when used in situations where perpendicular measurements cannot be taken. Where applicable, the project will investigate and identify potential solutions through the use of surveying techniques and instrument knowledge to improve the dependability of this technology.

PROGRAMME: (*Revision 1, 22 March 2009)*

1. Investigate prior research and other background information into prism-less total stations, targeting similar studies requiring high accuracy results.

2. Critically evaluate any available techniques or information relating to the use of prism-less total stations.

3. Analyse the properties of a specific prism-less instrument and compare to an instrument from a different manufacturer, to determine possible variation in results due to signal differences.

4. Establish via field-based assessment, a number of realistic examples to demonstrate that the instrument can give false readings. An examination will be undertaken to identify the reasons for these results.

5. Design a number of techniques to enable the accurate use of prism-less equipment.

6. Compare results from the use of the new prism-less techniques against both accepted values and results using existing prism-less techniques.

7. Submit academic dissertation on the research.

AS TIME PERMITS:

8. Determine if these findings hold true for other instrument types and makes.

AGREED:

______________________Student   _________________________Supervisor

Date   Date

_______________________Examiner

Date

Appendix B

TGO Raw Stake-out Results

Project : USQ angle inidence1

User name	Leigh	**Date & Time**	2:28:45 PM 22/08/2009
Coordinate System	LOCAL COASTAL GRIDS	**Zone**	GCG94
Project Datum	ITRF		
Vertical Datum		**Geoid Model**	AUSGEOID98 (Australia)
Coordinate Units	Meters		
Distance Units	Meters		
Height Units	Meters		

Point listing

Name	Northing	Easting	Elevation	Feature Code
900r	3999.997	299.997	10.000	R
901a	3994.072	313.437	9.931	INSTB
2000	3988.752	321.223	10.123	s64 drfl w1
2001	3993.645	321.434	10.110	s64 drfl w2
2002	3998.478	321.647	10.109	s64 drfl w3
2003	4003.487	321.867	10.040	s64 drfl w4
2004	4008.391	322.085	10.024	s64 drfl w5
2005	4012.101	322.249	10.013	s64 drfl w6
2013	3988.752	321.223	10.123	s64 drfl w1
2014	3999.996	299.998	9.902	900r
900	4000.000	300.000	10.000	INST
899	?	?	?	BS
1000	3988.747	321.226	11.173	W1 FLATPRISM
1002	3993.643	321.434	11.160	W2 FLATPRISM
1004	3998.476	321.644	11.159	W3 FLATPRISM
1006	4003.480	321.862	11.089	W4 FLATPRISM
1008	4008.379	322.079	11.073	W5 FLATPRISM
1010	4012.084	322.241	11.062	W6 FLATPRISM
1012	3994.073	313.438	9.932	901A
1100	3988.738	321.222	11.171	W1 -30PRISMAT-10
1101	3993.639	321.433	11.159	W2 -30PRISMAT-10
1102	3998.478	321.645	11.158	W2 -30PRISMAT-10
1103	4003.490	321.863	11.089	W4 -30PRISMAT-10
1104	4008.394	322.077	11.073	W5 -30PRISMAT-10
1105	4012.106	322.238	11.063	W6 -30PRISMAT-10
1200	3988.749	321.227	11.173	W1 DR
1201	3993.646	321.434	11.160	W2 DR
1202	3998.478	321.645	11.158	W3 DR
1203	4003.483	321.863	11.089	W4 DR
1204	4008.382	322.078	11.073	W5 DR
1205	4012.086	322.241	11.063	W6 DR
1500	3988.750	321.227	10.123	X DRFL W1
1501	3993.645	321.435	11.110	X DRFL W2
1502	3998.477	321.645	11.110	X DRFL W3
1503	4003.481	321.862	11.040	X DRFL W4

1504	4008.377	322.077	11.024	X DRFL W5
1505	4012.083	322.240	11.014	X DRFL W6
3000	4019.241	322.428	10.027	R
1513	3988.749	321.136	10.192	SIDE 90MMOSW1
1514	3993.644	321.344	10.189	SIDE 90MMOSW1
1515	3998.476	321.556	10.183	SIDE 90MMOSW1
1516	4003.482	321.775	10.113	SIDE 90MMOSW1
1517	4008.380	321.991	10.100	SIDE 90MMOSW1
1518	4012.084	322.154	10.088	SIDE 90MMOSW1

Back to top

All staked points - As staked

Project : USQ 6sept09 Angle of Incidence2

User name	Leigh	**Date & Time**	4:33:44 PM 25/09/2009
Coordinate System	Default	**Zone**	Default
Project Datum	WGS 1984		
Vertical Datum		**Geoid Model**	Not selected
Coordinate Units	Meters		
Distance Units	Meters		
Height Units	Meters		

Name	Code	Design Northing	Design Easting	Delta North	Delta East	Cut/Fill
5017	901	?	?	0.000	0.002	0.002
5101	5001	?	?	-0.003	-0.002	-0.005
5102	5002	?	?	0.000	-0.001	-0.005
5103	5003	?	?	-0.003	0.000	-0.005
5104	5004	?	?	-0.002	0.000	-0.005
5105	5005	?	?	-0.041	0.020	-0.007
5106	5006	?	?	-0.005	0.002	0.001
5107	5007	?	?	-0.005	0.003	-0.006
5108	5008	?	?	-0.003	0.003	0.004
5109	5009	?	?	-0.007	0.007	0.001
5110	5010	?	?	-0.005	0.007	-0.006
5111	5011	?	?	-0.008	0.008	-0.004

5112	5012	?	?	-0.006	0.009	-0.006
5113	5013	?	?	-0.003	-0.001	-0.007
5114	5014	?	?	-0.438	-0.227	-0.033
5115	5015	?	?	-0.001	-0.001	-0.003
5116	5016	?	?	-0.005	-0.002	-0.006
5902	901	?	?	0.002	0.005	0.000
4101	5001	?	?	0.001	-0.002	-0.005
4102	5002	?	?	0.001	-0.002	-0.005
4103	5003	?	?	0.002	-0.003	-0.005
4104	5004	?	?	0.002	-0.002	-0.005
4105	5005	?	?	-0.012	0.004	-0.006
4106	5006	?	?	0.001	-0.003	0.003
4107	5007	?	?	0.003	-0.005	-0.005
4108	5008	?	?	0.003	-0.005	0.004
4109	5009	?	?	0.003	-0.004	0.002
4110	5010	?	?	0.005	-0.006	-0.005
4111	5011	?	?	0.001	-0.006	-0.002
4112	5012	?	?	0.005	-0.009	-0.004
4113	5013	?	?	-0.001	-0.001	-0.006
4114	5014	?	?	-0.051	-0.027	-0.008
4115	5015	?	?	-0.007	-0.007	-0.003
4116	5016	?	?	-0.009	-0.009	-0.006

Points

Project : USQ silo 050709

User name	User	**Date & Time**	8:47:11 AM 25/07/2009
Coordinate System	Site	**Zone**	Default
Project Datum	WGS 1984 (1)		
Vertical Datum		**Geoid Model**	AUSGEOID98 (Australia)
Coordinate Units	Meters		
Distance Units	Meters		
Height Units	Meters		

Point listing

Name	Northing	Easting	Elevation	Feature Code
1000	100.007	103.651	103.298	prism1mm
1001	99.972	103.647	102.596	prism1mm
1002	100.001	103.653	102.072	prism1mm
1003	99.954	103.650	101.284	prism1mm
1004	99.956	103.656	100.053	prism1mm
1005	100.007	103.657	103.302	1000
1008	100.001	103.649	102.069	1002
1009	99.972	103.647	102.595	1001
1012	99.954	103.648	101.283	1003
1013	99.956	103.653	100.053	1004
1020	100.007	103.653	103.299	reflectorless
1021	100.007	103.656	103.301	reflectorless
900	100.000	100.000	100.000	arbit

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Appendix C

Extended Abstract

Paper Number_________

COURSE: ENG 4903, PROFESSIONAL PRACTICE: Project Conference, 2009.

AN INVESTIGATION INTO THE ACCURACY, PRECISION AND RELIABILITY OF REFLECTOR-LESS TOTAL STATIONS.

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Supervisor:

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Despite the vast technological advancements in equipment, the survey industry continues to struggle with the collection of data relating to inaccessible points. While the introduction of reflector-less total stations has meant that inaccessible points can now be measured with relative ease, there is some question as to the accuracy and reliability that can be achieved with such equipment.

The object of this study is to determine likely limits for reliability of reflector-less instruments especially in relation to measurements with large angles of incidence, but also looking at the vagaries caused by differing materials and beam divergence. The study has been carried out in various locations using Trimble S6 and S8 reflector-less total station equipment to a variety of surfaces materials and shapes.

While the results of this study have not yet been fully analysed, early indications suggest that angle of incidence of the measurement beam to the surface of the measured material has a large influence on the accuracy of that measurement. Also, beam divergence can cause errors as the distance from the instrument increases. The newer, more accurate (instrument's specifications) version of the S6, the S8, whilst only tested on some of the trial sites, shows increased reliability of distance measurements.

These results confirm anecdotal evidence from the surveying industry, of both personal and colleague's experience, and seems due largely in part to errors caused by measurements taken with large angles of incidence. To date, to some extent, if the instrument can make a measurement, it will be accepted as true. For coarse measurements, it seems that this approach is acceptable, but when accuracy of only several millimetres is allowable, surveying techniques become important.

In the search for accurate survey results from inaccessible points, it becomes necessary to ensure that crucial measurements are checked as well as giving the best chance of an accurate measurement by setting up as square as possible to the object's surface, even if this requires a multitude of separate instrument setups and extra time.

Appendix D

Project Appreciation (in part)

8 Project Appreciation

8.1 Ethics & Consequential Effects

The Spatial Sciences Institute (SSI) has a Code of Ethics, of which Members must agree to abide, that is based in the values of:

- Competence,
- Truth,
- Social justice, and
- Ethical behaviour.

Whilst based upon these values, the Code states that members must act with responsibility to the community, their profession as well as other members.

Tenet #4 states, "Members shall provide services and advice carefully and diligently only within their areas of competence". In accordance with this, methodology and assumptions used throughout this study will be clearly defined and stated. The results found will be based upon only the data that is collected. Also, at the beginning of the dissertation is a statement stating clearly that this is an educational process only.

According to Collins Australian Dictionary (2004), 'ethics' can be described as the moral fitness for a course of action. None of the works I will be doing as part of this dissertation goes against any publicly accepted morals or the ethics as set out by neither the Spatial Sciences Institute nor the University of Southern Queensland.

8.2 Project Methodology

8.2.1 Overview

This project will be broken into three major parts, the literature review, the fieldwork, and the written analysis of results. The literature review will involve researching the background of the topics involved, previous work done and theories behind the technology and procedures. The fieldwork will involve mainly a reflector-less total station and will utilise both conventional measurements and reflector-less technology. The work will establish a recognised and accepted value for a specific structure by using various established survey techniques and checks. There then needs to be a comparison with what results can be achieved with reflector-less total station measurements. As different shaped structures all have their own measuring issues, several examples will be tested, including the use of different materials. Then, once the field data has been collected, it will be analysed to determine to what accuracy reflector-less measurements can give.

8.2.2 Background

The background review is a largely internet based search due to the fact that Geraldton does not have a university the closest useful texts are at Curtin University in Perth. The search for background data should come from the following:

- Surveying journal articles such as Position: The Australasian Magazine of Surveying, Mapping and Geoinformation,
- Previous research done available on the internet,
- Papers available through the USQ library,
- Trimble specifications,
- SSI – Spatial Sciences Institute
- Surveying and relevant text books as available and through USQ.

The review needs to cover the technologies used like reflector-less total stations, surveying methodologies, and the technicalities of reflector-less measurements.

8.2.3 Fieldwork

The fieldwork will take some planning to ensure that everything is done properly. This preparation firstly needs to finalise the structures to be targeted, to ensure that they are measurable using prismatic techniques and are a safe workplace. They also need to sufficiently different in shape and/or material, and are a permanent structure that will remain unchanged if extra measurements need to be taken.

The number of sites has yet to be determined, but will likely involve at least two different places, both as a check on the findings, and to determine differences between different surfaces. Firstly, the pattern of the measurements will be marked, having both perpendicular-to-wall measurements and measurements on the skew. Ideally, skew measurements will need to be both horizontally and vertically.

The accurate position of the marked points then needs to be established. This will involve a range of techniques using baselines, and mini-prisms that are designed for use against walls. Two obvious techniques are setting up a long way from the wall and using a prism to every mark, and setting up a baseline close to the wall and then using a tape and optics, determine each mark's offset from the flat surface. The first technique will eliminate any setup errors, whilst still being able to measure the points from a relatively perpendicular position to the wall, while the second technique will give very accurate results.

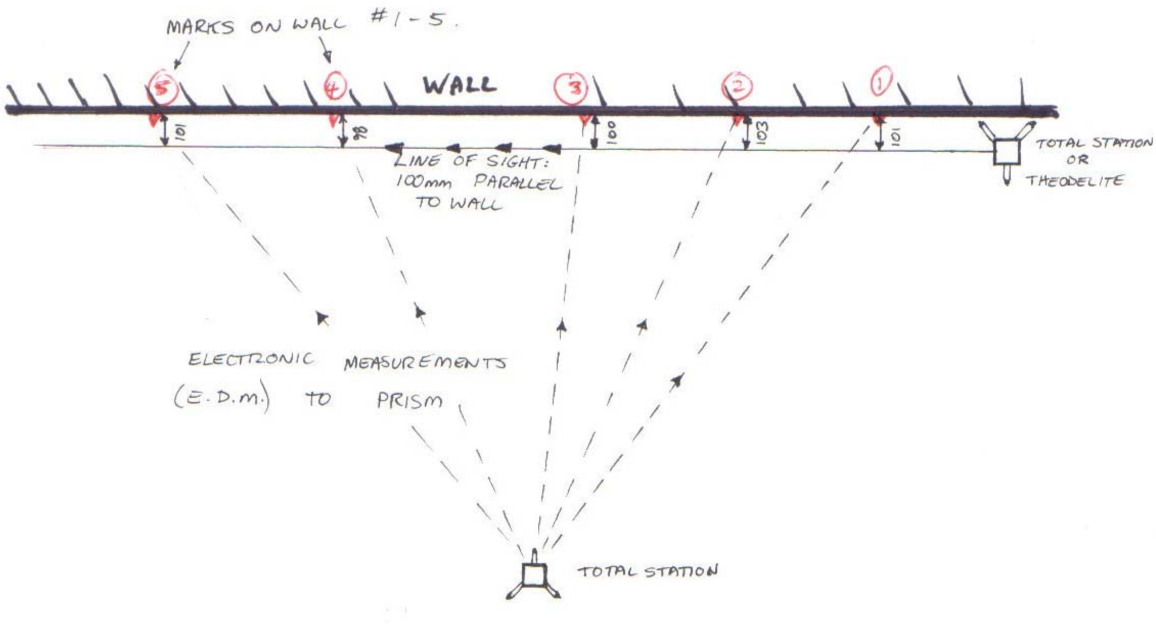


Figure 13: Establishing accurate control points on wall.

Once the marks positions have been confirmed, then the reflector-less instrument will be used to make a number of measurements using several different variations. These will include using Face Left (FL) - Face Right (FR) averaging, close and long distance measurements, and a variety in the 'angle of incidence' to the wall. Where possible, a variety in vertical angled measurements will also be recorded.

Another test is to see how accurately corner measurements can be measured for both internal and external corners. This is more of a test about the diameter of the reflector-less beam than anything else, but is still important to show what errors can be made and therefore avoided. A measurement will also be taken to a bolt that is on a wall as a second check of beam diameter. A reflector-less measurement with a close proximity to the bolt will be more likely to get an accurate result than measurements from a more distant position. This is due to the divergence of the signal.

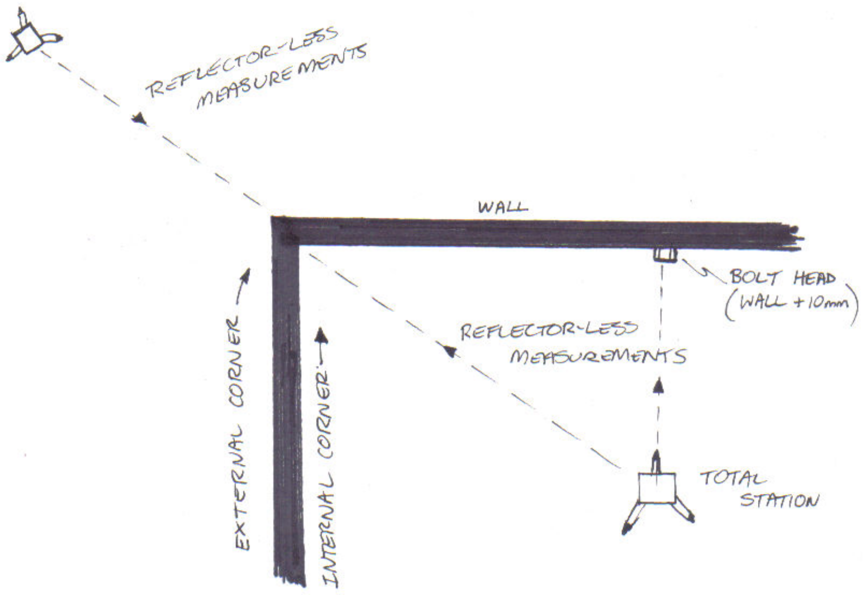


Figure 14: Reflector-less measurements to internal and external corners.

8.2.4 Analysis

The analysis of fieldwork will comprise of four main parts;

- The processing of the 'control' coordinates (those coordinates derived by conventional means that will be accepted as correct.)
- The processing of the reflector-less data to determine its three-dimensional value compared to the accepted values.
- A conclusion as to the accuracy of reflector-less measurements in differing circumstances.
- Develop a number of techniques to deal with the inaccuracies found in the investigation. Alternatively, in the case of a lack of viable techniques, establish why reflector-less measurements are not ideal in some cases.

Using current data processing software and instruments, it is quite simple to compare different coordinates, even in the field, using stakeout software. The analysis may prove to lease some ambiguities, in which case extra fieldwork will be done to prove a result.

8.3 Risk Assessment

8.3.1 General

This project involves much office time, in the background literature review and afterwards in preparation for the fieldwork and in writing up of the results. Risks here are minimal, especially in comparison to the fieldwork where the general public is involved, introducing traffic (vehicle, bicycle and pedestrian) and the risks introduced in driving, and manual labour.

The aim of a risk assessment is to decide whether a job can be done safely, and if not, control of the risks to lower the likelihood and/ or consequences so that there is minimal dangers. For example, road works are dangerous for those involved but with the introduction of traffic management the risks are lowered greatly. The same goes with wearing a hat in the sun. There are not just single solutions or best solutions. Risk controls can be used together to decrease risk.

8.3.2 Office Risk Assessment

Office risk still exists even though the risks are relatively minor. As it is a common workplace for me, no risk assessment has been included here. Risks involved though include:

- Injuries caused by incorrect seating and posture
- Travel to and from the office

These are all valid injuries and risks but with minor consequences. Risk assessments are generally done to new and changing work environments, but there is generally little change in office environs.

8.3.3 Fieldwork Risk Assessment

When conducting a risk assessment, it is important to be aware of any risk to others such as pedestrians, and not just the field crew themselves. Fieldwork risks include:

- Manual lifting of heavy objects such as batteries and equipment boxes
- Possibly working near car parks or roads with low-volume traffic
- Travelling to and from office and site
- Damage to pedestrians (and equipment)

Situations like this occur daily for me as a surveyor so the risk assessment below is an accurate reflection of the risks involved in such a project. As the sites of the project are yet to be finalised, some changes may occur at that time, most likely with the amount of traffic. As the fieldwork will mostly be done on the weekend, traffic should be of a low to medium volume only.

RISK MATRIX

		LIKELIHOOD			
CONSEQUENCE	unlikely	possible	probable	RISK RATING AND RESPONSE	
minor	*low*	*low*	*medium*	*low*	ensure risks don't change
major	*low*	*medium*	*high*	*medium*	if possible lower the risk or eliminate risk.
catastophic	*medium*	*high*	*high*	*high*	use controls change likelihood or consequence

RISK ASSESSMENT

manual lifting	*low*	unlikely	minor
traffic	*low*	unlikely	major/catastrophic
equipment damage	*low*	unlikely	major
travel	*low*	unlikely	major/catastrophic
onlooker injury	*low*	unlikely	minor

8.4 Resource Planning

8.4.1 Field Equipment

As approved by my employer Ed Delfos of the consulting survey firm Hille, Thompson and Delfos (HTD or HTD Surveys) I have full access to the full range of surveying equipment that is required to complete this Project including Trimble S6 reflector-less total stations as well as all ancillary equipment.

Ancillary equipment includes vehicle, tripods, tribrachs, targets and safety equipment.

8.4.2 Office Equipment

As approved by my employer Ed Delfos of the consulting survey firm Hille, Thompson and Delfos (HTD or HTD Surveys) I have full access to the computers and software for processing of field data, and any search data required.

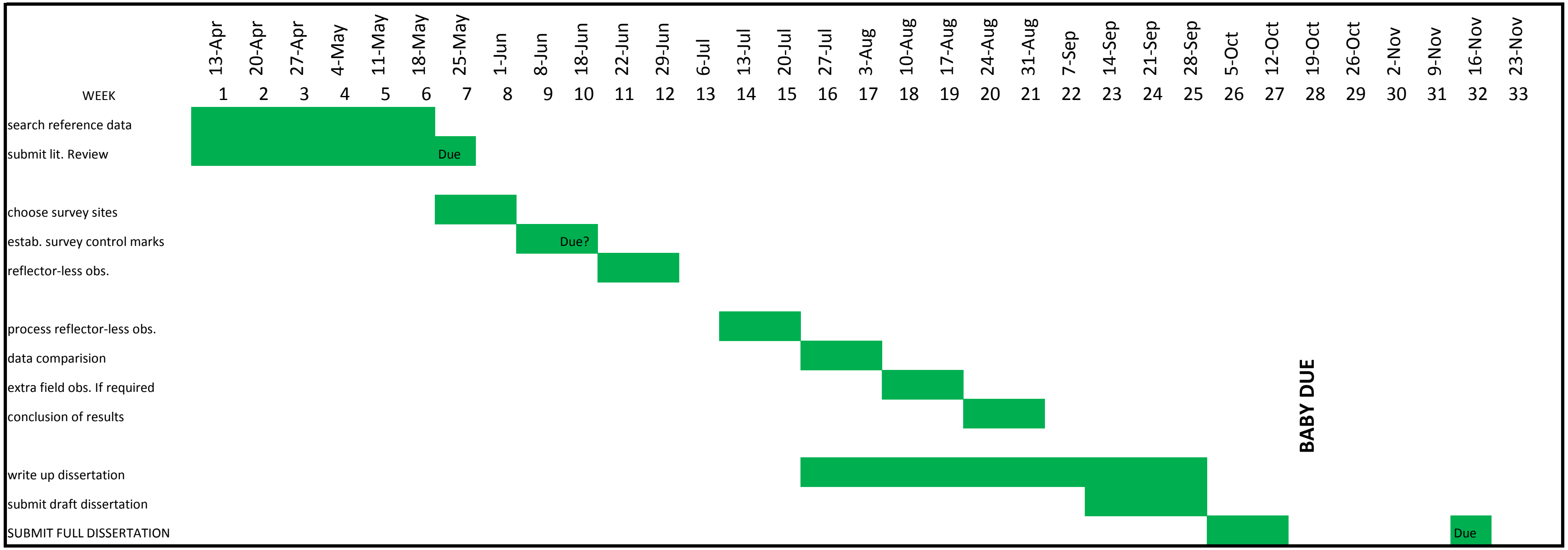
The software used will be the Trimble processing package TGO but may also include SDR Map and AutoCad, especially for the production of plans.

8.5 Project Timeline

At this stage, I am unsure of the submission requirements for second semester. These, depending upon their requirements, will be fitted in as best they can.

Some things overlap, especially the write-up with the data analysis, in the attempt to keep the findings clear.

The chart below is produced as a guide only and will hopefully help to keep things running on time.


WEEK
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
13-Apr 20-Apr 27-Apr 4-May 11-May 18-May 25-May 1-Jun 8-Jun 18-Jun 22-Jun 29-Jun 6-Jul 13-Jul 20-Jul 27-Jul 3-Aug 10-Aug 17-Aug 24-Aug 31-Aug 7-Sep 14-Sep 21-Sep 28-Sep 5-Oct 12-Oct 19-Oct 26-Oct 2-Nov 9-Nov 16-Nov 23-Nov
search reference data
submit lit. Review
Due
choose survey sites
estab. survey control marks
Due?
reflector-less obs.
process reflector-less obs.
data comparision
extra field obs. If required
conclusion of results
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