University of Southern Queensland

Faculty of Health, Engineering and Sciences

Investigating the Accuracy of Terrestrial Laser Scanning within a Rail Environment

A dissertation submitted by

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Abstract

Today technology is so advanced and has reached a point where current regulations need to be reviewed and new technologies need to be incorporated in legislation. For this to take place in the Terrestrial Laser Scanning (TLS) field we need to provide evidence of proven and verified instrument accuracy. The proven working accuracy other than a specification in a product brochure needs to be documented for TLS's to be adopted in Railway industry that requires accurate data.

The aims of this investigation is to document working accuracies for TLS and determine if the instrument conform with Sydney Trains specification by calibrating a scanner. The existing Track Control Marks (TCM's) represented by very small Survey Steel Pins (SSP's) installed on the face of steel masts in the rail corridor will also be tested to see if they can be scanned accurately . The scan time to capture a rail track scene will also be compared with survey points measured using current Survey Total Station (STS) methods.

Various custom targets using colour tones and material found in the rail corridor have been constructed and tested for scanning useability. An indoor self calibration room has been established which included the setup of a ground control traverse. A target network has been designed and seventy targets have been installed and signalised. The Leica TS15 and TS30 STS, have been used to signalise the seventy targets. The calibration targets are a mix of Faro and Leica black and white checker pattern scanner specific targets. The targets closest to the floor have had an SSP fitted in the centre of the checker pattern target for testing. The indirect method of TLS self calibration method was used by the Leica P20 ScanStation and the Faro Focus 3D X330 scanners, to scan all the targets form three scan positions. The distances between all the installed target have been measured with a tape for independent checks on the final 3D positional coordinates of the targets. The two scanners were setup in the rail corridor and scanned a section of rail track. This section of track was also measured by a STS using current Sydney Trains conventional methods. Existing SSP's fitted with scanner targets were scanned and used for the registration of these two point clouds.

It was found when the STS data compared to the Scanners data, the 3D positional coordinates were within +-2 millimetres. This result verifies that the two TLS's are as accurate as a STS therefore conform with Sydney Trains specifications and can be used in the rail corridor for survey measurements. The SSP testing was successful. They can be scanned and used in the registration process of a point cloud. The mix use of scanner targets with different manufacturer scanner was also successful. When the measured data from a section of rail tract was scanned and surveyed conventionally, the data was compared and the data once overlayed were identical. This test also documented the significant difference in time for completing a survey in the rail corridor using a scanner and STS. The documented ability to measure fast and with verified accuracy using a TLS from a safe place within the rail corridor without encroaching into the danger zone from a safety perspective this is a significant development.

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Certification of Dissertation

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

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

Stavroula Agoritsas

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Signature

29/10/2015

Date

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Chapter One - Introduction

1.1 Project Background

Terrestrial Laser Scanning (TLS) is not a new technology but there is no official legislated procedure to verify its accuracy. Current regulations need to be reviewed and new technologies need to be incorporated in legislation. "A Surveyor must not use any equipment in making a survey unless the surveyor knows the accuracy obtained by its use" (NSW Surveying and Spatial Information Regulation 2012). "Verification is a test to confirm that the accuracy attained by a measuring instrument is within allowable accuracy limits as defined in a specification or as required by legislation"(NSW Surveyors General's Direction No 5 Verification of Distance Measuring Equipment 2009). For this to take place in the TLS field we need to provide evidence of proven and verified instrument accuracy. The proven working accuracy other than a specification in a product brochure needs to be documented for TLS's to be adopted in surveying applications that require accurate data such as the railway environment. This means the TLS's just like the Survey Total Station (STS) need to be calibrated and the data analysed to determine their accuracy.

Sydney Trains is a New South Wales government agency and operates all passenger rail services in the metropolitan Sydney area. The organisation recently went through a restructure. This initiated and encouraged innovation and use of advanced technologies to be assessed and introduced to current survey methodology when undertaking survey work on track. Discussion in my workplace of ideas to do survey work on track safely with limited human resources lead me to investigate TLS within the rail corridor.

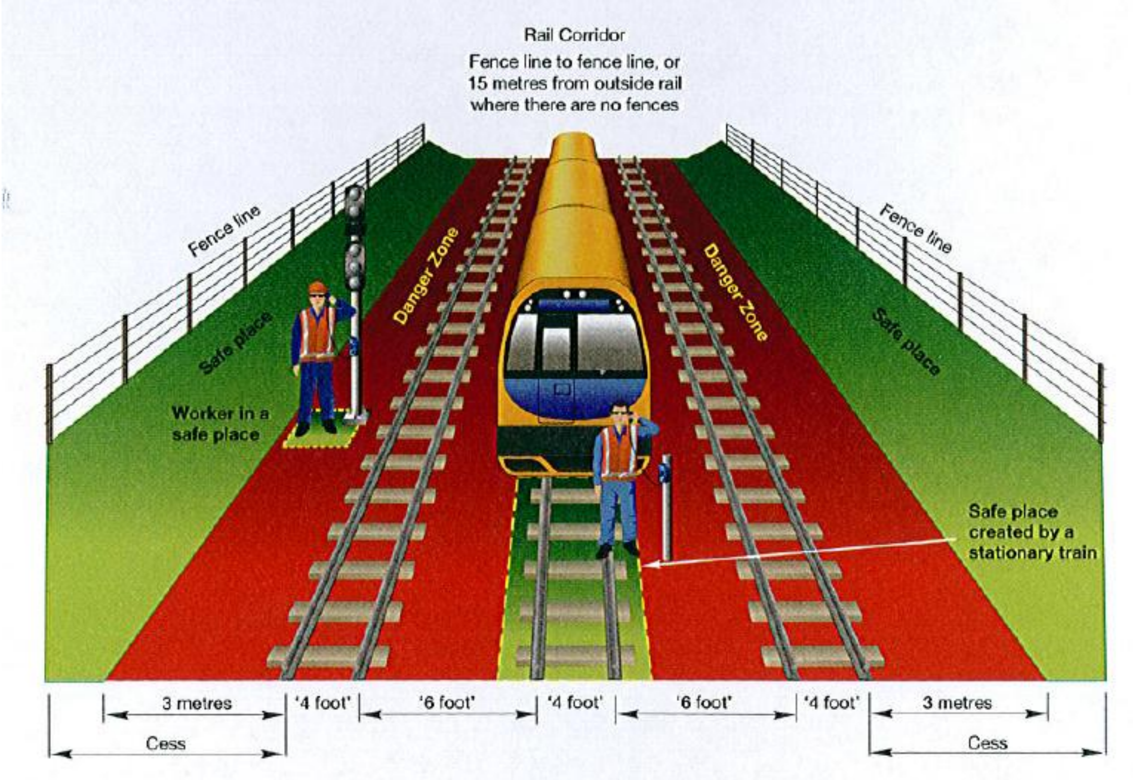


Figure 1.1 Qualified workers in safe places within the rail corridor.
(Source: Sydney Trains Network Rules NGE200 2014)

Currently the most common level of protection within the rail corridor to undertake survey work in the danger zone is lookout working. The danger zone as shown in Figure 1.1 is all space within 3 meters horizontally from the nearest rail any distance above or below this 3 meters. A safe place is a place where a person and their equipment cannot be struck by rail traffic. For a survey to be done two qualified safety personnel- nominated as lookouts, and the survey crew (a minimum of two qualified people three preferred) are required. A qualified worker in the rail industry means a worker certified as competent to enter the rail corridor and a holder of a current Rail Industry Safety Induction (RISI) card. The lookouts must keep watch for all rail track approaching the worksite from any direction and warn workers immediately if rail traffic approaches the worksite. A member of the survey crew usually the Surveyor or one of the safety personnel will also be the protection officer. In Figure 1.2 (a) on the left, a survey crew located at Harris Park 22 kilometers west of Sydney, is placing a survey prism on the overhead wire to take a measurement in the danger zone. Photos (b) in the middle and (c) on the right, also in Figure 1.2 show workers off the track and in a safe place with their lookout waiting for the approaching train to pass and clear their worksite . This personnel configuration changes on a daily basis. Additional lookouts might be required or the next level of protection will need to set up depending on the type of survey, scope and track location. For detailed information about rail safety procedures followed during this research refer to Appendix B.

Figure 1.2 Sydney metropolitan survey job sites.

This dissertation is not in any way investigating replacing the STS with a scanner to do all track surveying. The focus of this research is to investigate scanning technology accuracy, so it can be used for fast, large volumes of data capture within assigned specifications and tolerance, from a safe place within the rail corridor.

1.2 Justification

A Terrestrial Laser Scanner is an instrument that can be used to collect three dimensional data just like a traditional Survey Total Station can. Within a railway corridor with trains running the TLS can measure the data without encroaching the danger zone parameters, as a Survey Total Station would.

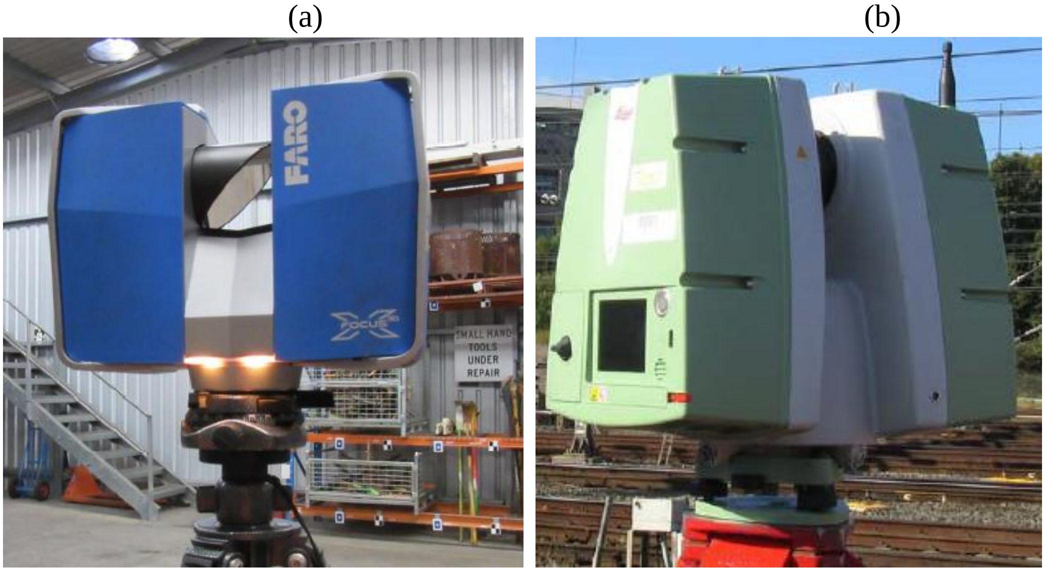


Figure 1.3 (a) The FARO Focus 3DX330 Scanner (b) The Leica P20 Scanner

A Terrestrial Laser Scanner can be setup in a rail corridor and left to measure in a safe place on its own, eliminating a lot of safety hazards. In Figure 1.3 both scanners a set up to scan a section of the rail corridor and there is no survey personnel standing in the danger zone. This equipment would certainly be accepted from a safety perspective it just needs to conform with Specification.

1.3 Project Aim

The dissertation aims to provide documented working accuracies for Terrestrial Laser Scanners. This will determine if the instrument conforms with Sydney Trains Engineering Specification SPC211-Survey. The research also aims to test if existing Track Control Marks (TCM's) in the rail corridor can be scanned accurately and used during the registration process of Scanning.

A TLS can capture data fast. Within a dangerous environment especially in a rail corridor the minimum time spent in the rail corridor is the best scenario.   This research is to document the scan time to capture a scene and compare the time with the time taken to measure the scene with current Survey methods and use of a Survey Total Station.

1.4 Objectives

The main objectives are as follows:

- Research background information on Terrestrial laser Scanners accuracy, calibration and current applications within a Railway Environment.

- Design and establish an indoor target reference network for the Self calibration of a Terrestrial Laser Scanner.

- Construct various custom targets using different types of material with a range of colours that best replicate a real railway environment. Install them, together with manufacture supplied scanner targets in the indoor calibration room.

- Complete the indoor Self calibration of a Terrestrial Laser Scanner by measuring to all indoor targets from three different scanner positions.

- Measure the same indoor targets with a STS from three setups to determine independent X, Y, Z values for the centre of each target.

- Scan a previously surveyed section of railway track in the rail corridor and compare the point cloud with the data measured using conventional surveying methods. Focus the comparison on particular structures such as overhead wires and rails.

- Analyse the scan time taken to capture a scene and compare this time with the current survey methods.

- Document the findings.

Optional objectives as time permits is to use more than one brand scanner, model the point cloud of the rail corridor scene capture and extract the overhead wires and rail data into a spreadsheet to represent the current railway overhead wiring report.

1.5 Summary

This dissertation consists of five chapters. Chapter One provides a background and justification of the project. The aim of the project is to calibrate a TLS and verify its accuracy , test the scanning ability of existing survey marks and document the scan time to capture a scene within the rail corridor. The outcomes of this study as outlined in Chapter 1, is to verify conformance of a TLS with Sydney Trains Specification so TLS they can be used for survey work within the rail corridor.

Chapter 2 presents a review of the literature ,which will determine the calculations and analysis procedures to calibrate and determine the accuracy of a TLS. Chapter 3 will outline the methodology and a detailed explanation of how each phase of this work was done. In Chapter 4 the results will be documented an discussed. Chapter 5 will formulate a conclusion and recommendations. In the final chapter areas of further research will be highlighted, which will lead to further understanding of the working accuracies of a TLS.

Chapter Two - Literature Review

2.1 Introduction

The demand for three dimensional data is great in many industries today. The use of complex technologies to produce a deliverable which is not only of a high quality but easy to understand and visually impressive in the form of a 3D model is now a necessity. The manufacturers of high end surveying instruments are constantly developing and releasing outstanding world class measuring technology to aid with industry demand. Terrestrial Laser Scanners is the focus area of this research and the instrumentation that manufactures want surveyors to embrace today more so then they have in the past.

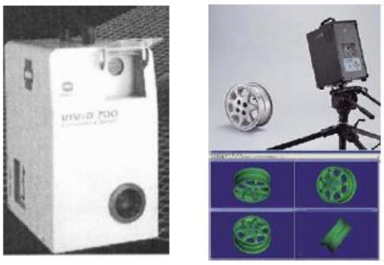
This chapter will begin with an overview of laser scanning history and highlight the areas that researchers have focused on in the past to develop an understanding and form a strategy as to how the calibration of such instrumentation in particular the TLS will be done and analysed. A brief explanation of the instrumentation that was used to complete this research will be covered. Information gained from the review of the literature of Terrestrial Laser Scanning, MultiStation and Survey Total Station measuring technology will also be described. Particular focus areas during the literature analysis, that previous researches have done most work on, will be identified. The methods and techniques that will be used to determine the systematic errors of a TLS, will be revealed.

2.2 History of Scanners

Arthur L Schawlow and Charles H Townes produced the first paper in 1958 that proposed the idea of a laser (*World Book encyclopaedia* 1975, p80). My literature review begins in 1998 with the first mention of a range imaging system known as a Range finder. This machine was capable of collecting three dimensional coordinate data from object surfaces. The Cyrax 2400 in Figure 2.1 was the world's first pulse laser scanner released in 1998. Cyrax Technologies was founded in 1993 and was the company that released the Cyrax2400 scanner, to be used by surveyors. Its range was 100m and data acquisition rate was 800 points per second (Inokuchi 1998). A high powered pulse allowed the user to do a survey without targets or reflectors - that allowed the measurement of inaccessible structures . It is important to mention that scanners available today have an average data acquisition rate of up to 1 million points per second. The Minolta VIVID 700 Rangefinder in Figure 2.1 was also released in 1998 to scan objects but at close range using triangulation measuring technology .

Cyrax
Cyrax 2400

Minolta
Minolta VIVAD 700



Optech
Optech ILRIS-3D

Callidus
Callidus CP3200

1998 **2000**

Cyrax
Cyrax 2500

Mensi
Mensi GS200

Reigal
Reigal LMS-Z420i

2001 **2003**

Leica (aquired Cyrax)

Leica HDS4500

Leica HDS300

Isite
Isite 4400LR

Z+F
Z+F Imager 5003

2004

IQSun
IQSun 880

Trimble (aquired Mensi)
Trimble GX

Leica
Leica ScanStation

Optech
Optech ILRIS-3DER

2005 **2006**

Figure 2.1 Time line of various Terrestrial Laser Scanners

Since the release of the world's first Terrestrial Laser Scanner, began an increasing interest from various industries which included processing plants and survey companies. Cyrax Technolgies released the next generation Cyrax 2500 series launched in New York in 2001. In 2004 the Leica HDS3000 followed, being the first laser scanner with dome scanning capabilities. At that time Leica and Zoller +Frohlich (Z+F) released the HDS4500 and the Imager 5003 phase scanners. For Leica this led to the unveiling of the ScanStation family of scanners which were faster, more efficient with survey functionality capabilities. The first ScanStaion was released in 2006. The year 2009 brought the release of the new look ScanStation C10 with complete Total Station capabilities. As time moved on TLS instruments were beginning to get faster, manage point cloud files more efficient and start to form an external shell that looked more like a Survey Total Station then just a black box.

In the first decade the manufactures concentrated on the Hardware and measuring technology. The next decade had to focus on how to manage extra large datasets and quality of measurements. In reference to Figure 2.1 over the years there has been various company acquisitions and re-branding of scanners. Faro Technologies and Leica Geosystems have managed to stand their ground and remain leaders in the laser scanning industry . In Australia the exclusive distributors of the Faro scanners is Position Partners and for Leica scanners it is C R Kennedy. This dissertation has used the Leica ScanStation P20 and the Faro Focus 3D X 330 Terrestrial Scanners for testing. The New Leica P40 ScanStation was released at the Hexagon conference in Las Vegas USA in July this year. The new scanners were sold out upon their release and due to the timing restrains for this project, availability of a P40 was not possible.

2.3 Terrestrial Laser Scanning

The literature review for this area of study has uncovered very complex pieces of equipment. Comparison of laser scanners is difficult because technical specifications and physical measuring principals are different (Frohlich 2004). The measuring technology and measurement principal needs to explained.

2.3.1 Measuring Technology

A Scanner emits a continuous laser beam but as it emits it rotates around its vertical axis. Oscillating mirrors move the beam up and down and this results in a sweeping beam over the area. As it emits, the beam hits an object and some of the objects energy bounces back to the scanner. If the return signal from the object is strong a distance can be calculated. The TLS measures to the objects surface not a prism. It is important to understand a scanners measurement is not the same as STS reflectorless measurement. A scanner cannot measure to one single point like the STS Figure 2.2

Figure 2.2 Examples of a single point measuremnt

A scanner actually performs a continuous sweeping beam measurement Figure 2.3.

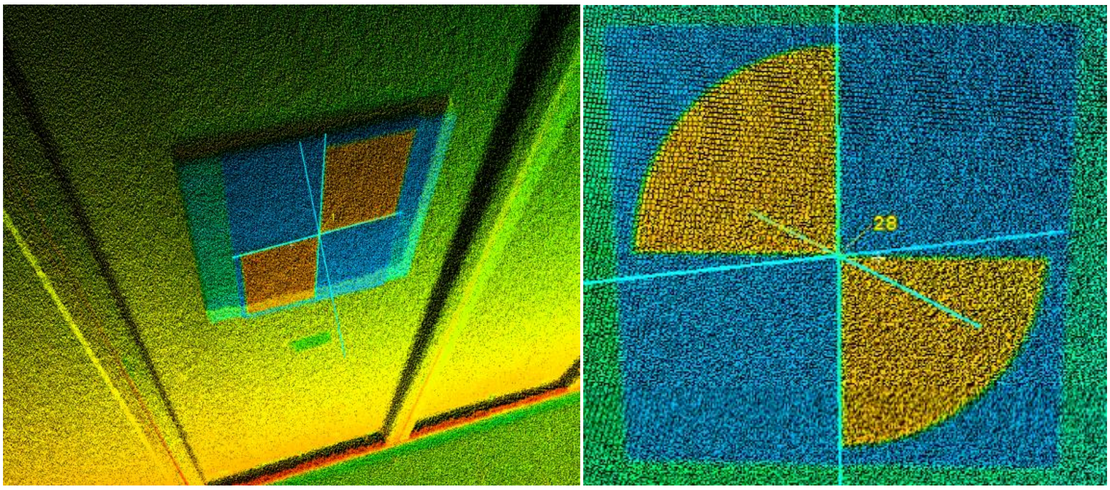


Figure 2.3 Examples of a TLS sweeping beam measurement.

2.3.2 TLS Measurement

Laser scanners today are available with five different types of measurement.

(a) Triangulation: The technology that allows individual objects to be scanned at close range with micrometer accuracy. Typical range is 0.5-2 meters. Used for industrial applications. This technology was not used in this research.

(b) Time Of Flight (TOF) : A laser pulse is sent out and a portion of this pulse is reflected from a surface and returns back to the instrument. The accuracy of this technology is based on its ability to accurately measure the time of the returning signal. The benefits of this type of measuring technology is the long range and lower scanning speed. This measurement is the most common in TLS's

(c) Phase measurement: The Phase technology emits a laser light at different frequencies. The difference between the emitted and reflected signals determines the distance of the object. They have a medium range capability but a fast data acquiring rate. Phase based scanning utilizes a constant beam of laser energy that is emitted from the scanner. A continuous wave (CW) modulation avoids measurement of short pulses, by modulating the power or the wavelength of the laser beam Hoffmeister (2014). The scanner then measures the phase shift of the returning laser energy to calculate distances. Systems can have three types of modulations:

   (i) Amplitude modulation (AM) - very high data rates (several hundred kHz) with short operating ranges. The intensity of the laser beam is actually amplitude modulated with a constant frequency.

   (ii) Frequency modulation (FM) - Data rates of (several kHz) The laser beam is linearly modulated, varying the frequency.

(iii) Pseudo-noise or polarization modulation(PN) - uses algorithms to modulate the signal.

(d) Waveform Digitising (WFD): Has the capability of digitising and recording the entire waveform of each emitted laser pulse through waveform digitisers Ussyshkin & Theriault (2010). This technology has mainly been used in mapping application for forestry and vegetation . WFD captures an enormous volume of rich data sets, with enormous amount of information and intensity for modelling vertical structure of surface objects and surface slope - roughness. In TLS WFD can provide better measurement performance Grimm et. al (2013)

(e) Airborne Lidar Scanning (ALS): The first Airborne Lidar system to use WFD was in 2004, the LiteMapper 5600 system with the Reigl LMS-Q560 laser scanner Hug & Ullrich & Grimm (2004). ALS falls outside the scope of this research but it must be mentioned because of its pioneering development of WFD technology. Leica's scanning range measurement is now based on WFD which was actually developed as far back as 1970s in Lidar Systems manufactured by Reigl Ussyshkin & Theriault (2010), Hug & Ullrich & Grimm (2004).

In the early periods of laser scanning, pulse scanners now known as TOF scanners focused on long range and high precision 3D data capture. As the year 2004 approached laser scanning measuring technology capabilities concentrated on speed of data acquisition and shorter ranges. Today laser scanners measure very fast, capture up to one million pts per second and work within a reasonable range at varied accuracies. The end user needs to understand and choose the scanners measurement mechanics carefully, to match their application.

2.4 Beam deflection

The dimensions of the environment that a TLS can scan, depends on the beam deflection method used. They are two methods:

Method 1: A profiling system that rotates a deflection mirror about the optical axis of the laser measurement system. A 360° profile measurement is achieved using the phase technology Frohlich et al. (2004). This system is paired with a moving platform.

In figure 2.4 (a) it can be seen the deflection of the laser occurs only in a vertical direction. In image (b) on the right a 3D point cloud is a result from one angle and a distance measurement and the actual motion of the laser scanner

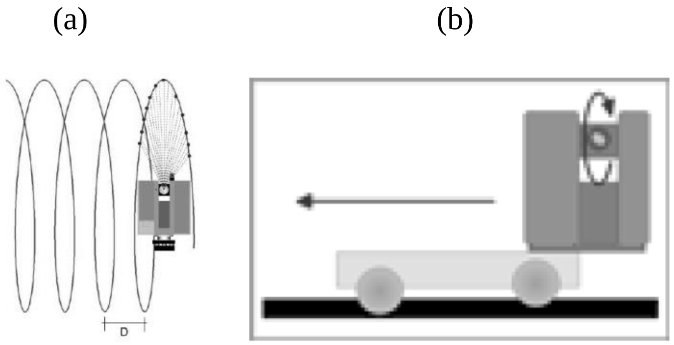


Figure 2.4 A profiler scanner
Frohlich (2014)

Method 2: An imaging system using a 2D deflection unit combined with a spot laser measurement system. The deflection unit allows imaging in horizontal and vertical directions. In this research the TLS instrumentation used is panoramic Figure 2.5, which is most common Gikas (2014). Panoramic scanners provide dome shape point clouds.

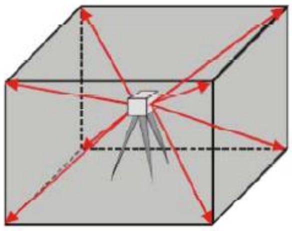


Figure 2.5 Type of scanners
Reshetyk (2009)

A panoramic view uses single oscillating mirrors which simultaneously rotates the system about its centre axis (Frohlich et al. 2004).There are two types, fixed head or camera like. Fixed head scanners is what the scanners for this research have and will be explained. The entire scanner head rotates about the vertical axis, in the horizontal plane. The Panoramic scanners mechanical increments of the scanning head are used to derive the horizontal angle measurements Reshetyk (2009).

2.5 Instrumentation

The instruments used in this dissertation testing are two Survey Total Stations, one MultiStation and two Terrestrial Laser Scanners.

2.5.1 Survey Total Station (STS)

The two STS instruments used are shown in Figure 2.6. On the left (a) The Leica TS15 and on the right (b) TS30. The manufacture specification can be found in Appendix C.

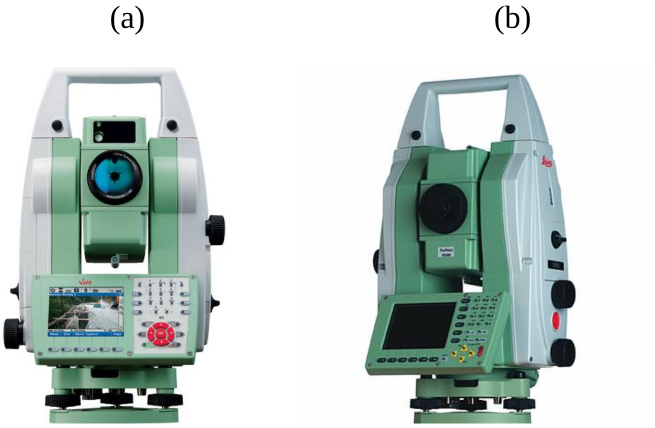


Figure 2.6 Leica Survey Total Stations

The main reason for using two is, for having and independent check on all the STS data as verification. A STS combines Electronic Distance Measurement (EDM) to determine the horizontal angle, vertical angle and distance measurement to a point and record it in a digital format. There are three distance measurement modes:

- Inferred Red (IR) - The Total Station with its built in EDM measure to a single point by emitting a laser beam from the instrument to a glass prism. The prism reflects this beam back to the instrument , a portion of the wavelength that leaves the instrument and returns, is calculated and results in a distance measurement from the instrument to the prism
- Reflectorless Red Laser (RL) - A distance measure without a reflector, directly to any surface to a single point.
- WFD technology has already been explained in this chapter. It is important to note the LeicaTS30 uses the WFD based technology when measuring. The literature review did not uncover to many papers on this measurement mode. This technology needs to be investigated further especially now that manufactures are introducing it in the Survey Total Stations.

2.5.2 Leica Nova MultiStation MS50

This instrument in Figure 2.7 uses new Electronic-Optical Distance Measurement system (EODM) based on Wave Form Digitizing (WFD) technology.

Figure 2.7 Leica MS50
C R Kennedy (2014)

WFD combines the advantages of TOF and phase-shift measurement. It is important to note WFD measurement is not a single measurement , it is short pulses with a frequency of up to 2MHz. The MS50's 3D laser scanner functionality uses standard Total Station workflows for setting up the instrument over a mark and which in turn allows easily for point clouds to be registered in the local coordinate system in the field. Manufacture specification are in Appendix D.

2.5.3 Leica ScanStation P20

The P20 is a TOF instrument using WFD technology. The P20 has a rotating scan-head and a rotating mirror that covers a 360° x 270° field of view (FOV) this is shown in figure 2.8. Manufacture specification in Appendix E.

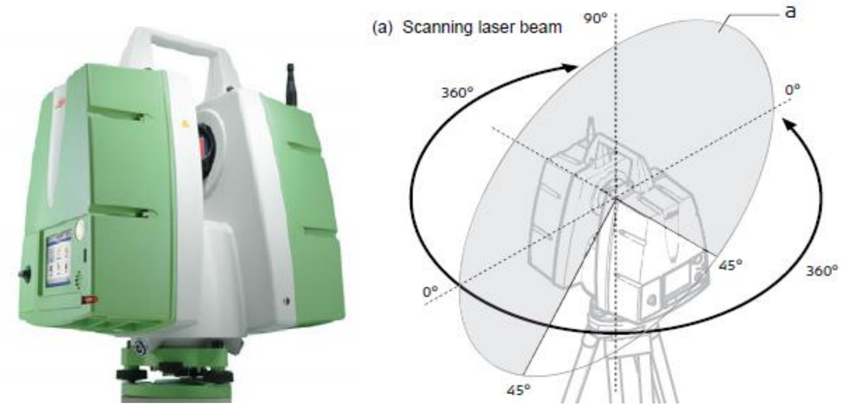


Figure 2.8 Leica P20 and Field of view
(sourced Leica Geosystems P20 manual)

2.5.4 Faro focus 3D X 330

The Faro shown in figure 2.9 is the smallest laser scanner ever manufactured and available in the market. It is a Phase measurement scanner. It was very difficult to find literature on this Faro TLS. Manufacture specification in Appendix F.

Figure 2.9 The Faro Focus 3DX330 and laser deflection
(source Faro)

2.6 Research on Terrestrial Laser Scanners

In just under two decades there has been three peak periods of a high volume of academic research papers in the field of Terrestrial Laser Scanners. The year 2007, 2013 and 2014 as highlighted in Figure 2.10. This finding is based on a sample size of 137 papers between the years 1998 to 2015, within the time frame restraints in undertaking and completing this dissertation.

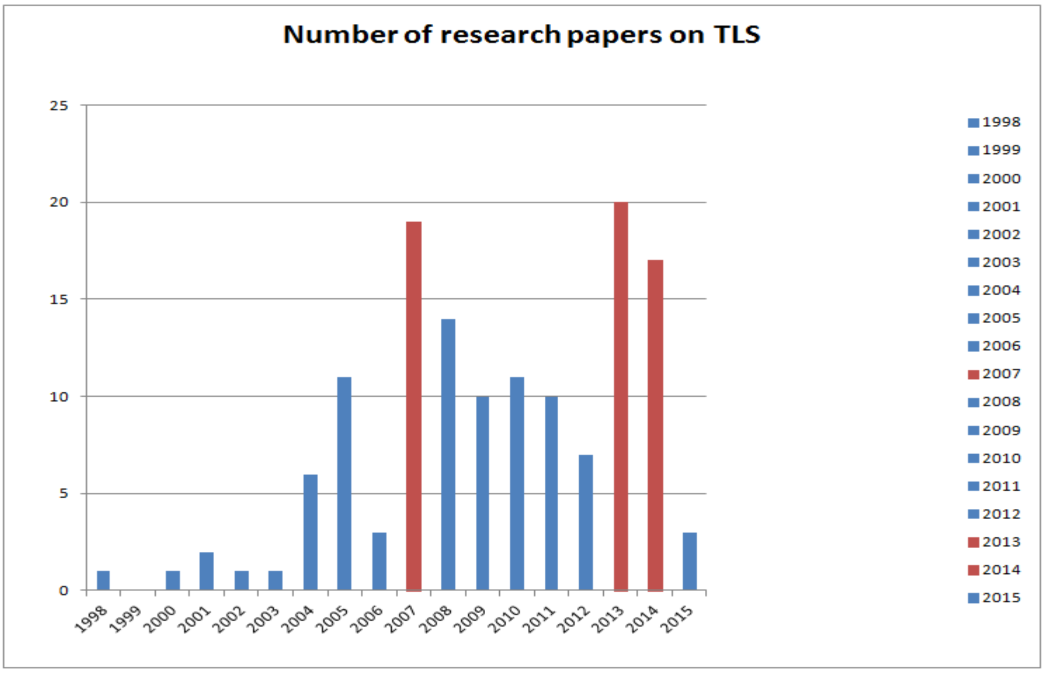


Figure 2.10 TLS research paper timeline.

The four main focus areas identified during this finding are shown in figure 2.11 and are:

- Accuracy with 38 papers and a 28% share of the research review
- Calibration with 26 papers and a 19% share
- Applications with 17 papers and a 12% share and General with 13 papers and only 9% share.

As it can be seen in Figure 2.11 there are four focus areas that stand out as explained above.

It is interesting to mention the most common applications for TLS has been shipbuilding Biskup & Arias & Lorenzo & Armesto (2007), open cut mining Wall (2009), road construction earthworks volume Slattery (2012), as-built surveys in tunnels using real time Tunnel Boring Machine (TBM) data Wu (2013), laser scanning integration with Building Information modelling (BIM), mapping and monitoring of historical artefacts and caves Coso (2014) and various monitoring deformation surveys Gordon (2007), Monserrat (2007), Nixon (2012) and Beshr (2013) and geology Alba & Longoni & Papini & Roncoroni & Scaioni (2005).The general category included papers that focused on TLS as an overall technology and explanation of scanning terminology and principals.

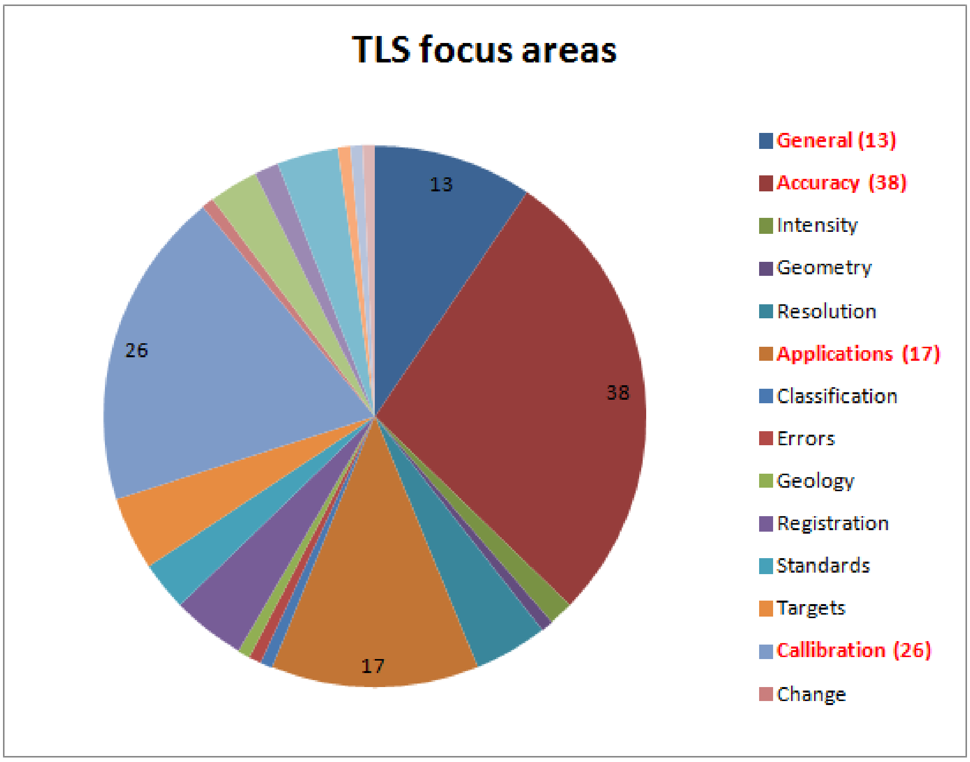


Figure 2.11 TLS research papers focus areas

Overall Terrestrial Laser Scanning needs more research and investigation from academics to help the end user understand the technology.

2.6.1 Verification Tests

Wooden spheres were used for verification testing in the early days of TLS Frohlich & Mettenleiter (2004). The centre of the spheres were coordinated and comparison of known distance and the calculated distance between two centres were made. Another verification test used 32 vertically placed cylinders, arranged in a square at the University of Essen. The accuracy of a number of scanners was checked by determining the radius of each cylinder Frohlich & Mettenleiter (2004).

2.6.2 Accuracy

The quality of the scanner measurement cannot be defined by looking at individual single measurements as you would with a Survey Total Station. Lichti (2000) completed the work of assessing the accuracy and resolution of a the I-Site pulsed Laser Scanner using an EDM calibration baseline. Due to Lichti et.al (2000) the uncertainty of the location of the instruments electronic centre, this method was not followed in this project. Another factor of not using a pillar baseline was resources. Time restrains on the availability of the scanners was also a factor. To design and set up a baseline for this project would not have been feasible .

Boehler in 2003 conducted a series of accuracy tests to determine systematic errors on various laser scanners, his methods are documented in detail in his paper. What is interesting to note is ranging scanners produce a variety of wrong points near edges. Using spheres as targets, the range between the targets can be measured. This measurement assuming the targets are at the same distance from the scanner is derived after the centre points have been modelled from the point cloud, this will generally indicate the angular accuracy of the scanner. With Terrestrial Laser Scanners accuracy depends on the following Frohlich (2004):

- the intensity of the reflected laser light
- reflectivity of the object surface
- angle of incidence
- surface properties

The angle of incidence effects an individual's point Signal to Noise Ratio (SNR). Litchti (2005) investigated the conformance of two scanners accuracy to Western Australia's Main Roads standard 67/08/436 Digital Ground Survey (DGS). Assessment of positional accuracies were made. The scanners used were a Riegal LMS-Z210 and then Cyrax2500. The positional accuracy of scanned features relative to the total station survey were made. Accuracy specifications were not meet. The scanner had no axis compensator. The features in the point cloud used for comparison had to be extracted manually, automation of this process would certainly have been more accurate. TLS point clouds can highlight the angular positional uncertainty due to beam width Lichti (2006). This can also manifest in edges, curved objects such as cylindrical pipes. Lichti in this research discovered a fine angular sampling interval does produce a high-resolution point cloud if the beamwidth is significant. Kersten & Thomas & Mechelke & Harald (2009) University based groups primarily carry out investigations on laser scanning systems. Abbas (2013) Defined the terms precision and accuracy. Precision is determined by referring to the manufactures specifications but accuracy has to be evaluated through deviation of nominal and real value Abbas et al. (2013). 3D accuracy is determined by a least square adjustment Wunderlich & Wasmeier & Ohlmann-Lauber & Schäfer & Reidl et al. (2013) and is an indicator of the quality of the measurement.

2.6.3 Calibration

They are two types of calibration that can be performed for the TLS, component and system calibration. Component calibration requires special laboratory equipment therefore can't be done by an individual. System calibration can be done as you only need a room with targets which is known as self calibration. The I-Site pulsed laser scanner was tested on an EDM baseline, located at Curtin university in Western Australia Litchti et al. (2000) . Reflectors were used as targets on each pillar. Due to the reflector being glass, the scanning of the prism created a halo effect, multi laser responses of the scanned target. This made it hard to determine an accurate centre for that target. For the calibration of laser scanner for this project this methodology was not adopted. Litchti & Harvey (2002) also discovered using surveying reflectors was no good. Most laser returns saturated the scanners photo detector. Harvey for his investigation used a Cyrax scanner.

Gordon (2004) discussed the two methods for georeferencing scan data.

- The direct method - scanner positioned over a known mark
- The indirect method - relies on locating the scanner in space using coordinated targets identifiable in the scanners Field Of View FOV.

Reshetyk (2006) performed a scanner self calibration. Targets were surveyed by a STS a very labour intensive task and the standard deviation of adjusted target coordinates were calculated. This method will be adopted as an independent check of the target centres from the TS15 and TS30 instruments in this research .

Garcia (2013) completed a geometric calibration of a TLS. LASEGIFLE software used for additional parameters (AP) modelling. The Methodology Garcia used was a reference network of point targets and spheres. Redundant measurements of these targets were collected with the TLS setup at different positions. This was a very good paper, with a good explanation of the calculation process. Hanke & Grussenmeyer & Grimm-Pitzinger & Weinold (2008) calibrated the Trimble GX which superseded the Mensi, using direct georefrencing. The GX had an active dual-axis compensator that corrects the horizontal and vertical angles during the scanning. Some of the findings were two scanners can have different additive constants. All the data measured by the scanner was not available , only distances. Abbas (2013) completed a self calibration on the Faro Photon 120 scanner. Abbas used seven scan stations, statistical analysis (t-test) showed all error models, the constant , collimation axis, the trunnion axis and the vertical circle index error in his findings.

2.6.4 Scanning Targets

Dold (2005) used Gaussian images for representing spheres for registration of a scan during his research. Registration by features was not available and artificial targets - spheres had to be used. The registration of artificial target such as spheres are detected automatically by a scanner algorithms Dold et al.(2005). Reshetyuk (2005) used retro reflective targets during a calibration of the Calidus laser scanner. When Reshetyuk tested targets made of retro reflective material, the high reflectivity of these targets during scanning caused a significant offset errors. They were actually pressed out of the wall in the point cloud.

Reshetyuk (2005) research undertook establishing a calibration field consisting of 20-25 coordinated targets placed on the walls , floor and ceiling and within the scanners FOV. Spherical targets were used as they are omnidirectional and are automatically recognised by scanning software. Reshetyuk in his paper determined the optimal diameter, that produced the most accurate sphere centre. The optimal diameter was determined to be 14cm . All the experiments were done at the Swiss Federal Institute of Technology in Zurich using the Imager 5003 and HDS3000. A calibration track line was also used. Reshetyuks approach could be applied when designing calibration procedures for scanners.

Kersten & Thomas & Mechelke & Harald (2009) used spheres as reference points during his research. The diameters were 76.2,145, and 199 millimetres. The material of the small ones was solid plastic and for the larger one hollow plastic with special surface coating. The centre position of spheres were determined from algorithms programmed in software such as 3Dipsos and then run through MATLAB software using an independent algorithm to check the centre coordinates of the same spheres. In Kersetns investigations accuracy evaluation was the measurement to an independent reference.

2.6.5 Standards

Lam (2006) was the first to state in his paper the ISO9001 all survey instruments including laser scanners must be calibrated before use and ISO1101. Gottwald (2008) refers to the ISO 17123 which is also referenced in the ST SPC211-Survey specifications. The VDI/VDE 2634 part III guidelines has used in Kersten(2009)

2.7 TLS Applications in a railway environment.

This research is focused on Terrestrial Laser Scanners, scanners that are static and scan from fixed scan position. Although this research is investigating TLS in the railway environment it is important to note, the first scanner for railway application was the PROFILER 6000-300 released in 1994 from Zoller + Frohlich (Z+F) in Germany. This scanner was specially designed for kinematic data capture for railway surveying vehicles (Frohlich 2004) .

In Figure 2.12 image (a) on the left was the first model, image (b) on the right is the current model of profiler scanners used for kinematic laser scanning (Z+F 2014).

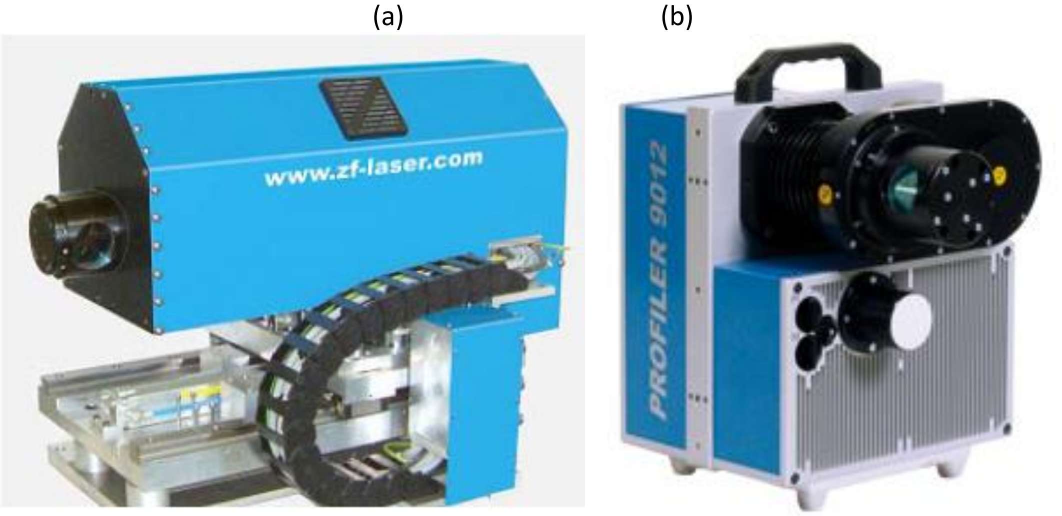


Figure 2.12 PROFILER 6000-300 & 9012 (Fröhlich & Mettenleiter 2004)

The profiler scanner changes its position as it acquires data, the measuring methodology is completely different to Terrestrial Laser Scanning. A kinematic (moving platform) profiler scanner, scans the surrounding environment from a moving position.

Milev (2007) discussed the extension of an existing kinematic measurement system to include a combine technology of GPS and TLS Figure 2.13(a), on the German rail corridor, for track alignment recording, maintenance and clearances.

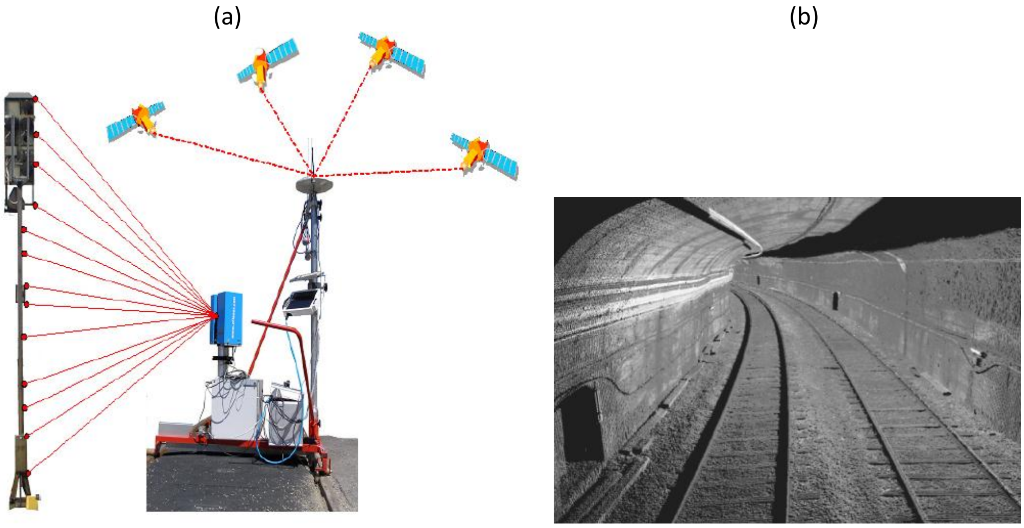


Figure 2.13 3D Multi sensor for rail maintenance
(source Milev (2007)

The system was made up of an Z+F Imager 5003 and GPS. The data required was track gauge and superelevation but the GPS/laser scanner captured the whole scene. This paper did not indicate any accuracy requirement. An image of the point cloud in figure 2.13 (b). Grafe (2008) investigated the combination of mobile laser scanning setup on a vehicle with a faro focus TLS together. The mapping of rail and road corridors was done but further researcher and the requirement for the calibration of the TLS was discussed.

Izvoltova (2013) highlighted the point that there has not been great experience with scanning rail track construction . The site location for this project was Slovak Republic on a ballastless section of track. A Leica C10 ScanStaion was used to scan rail track near a tunnel. A point cloud of the track is shown in Figure 2.14 (a) and the CAD extraction of rails in (b)

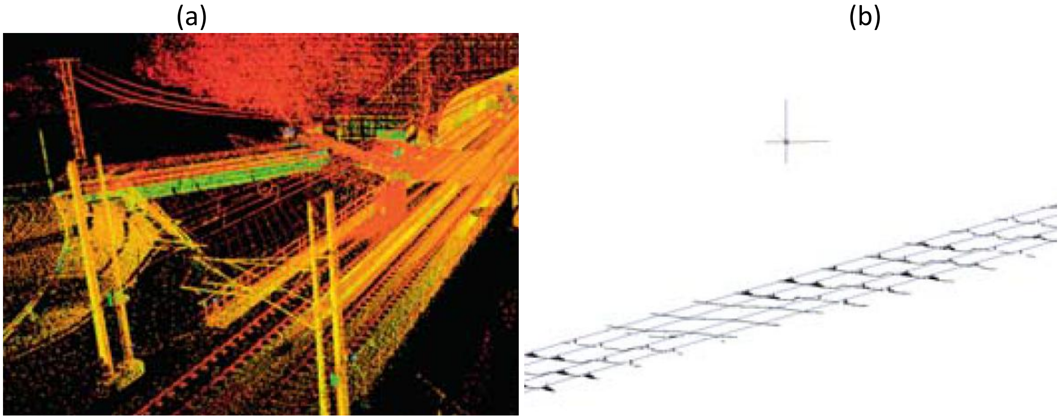


Figure 2.14 Point cloud at 102.360km

3D data was collected processed but not connected to survey control. The data's conformance to track specifications was unknown. This is the first paper in the literature review that has highlighted the aim of my research work which is conformance.

Soni (2014) researched the extraction of rail track for monitoring deformation during track works at London Bridge Station. A point cloud was captured and fitted over a rail track profile for comparison. Monitoring surveys were existing but there was a requirement for a backup system for quick checks. The web and foot of the track will need to be captured and extracted accurately. Mobile scanning has been used in the rail corridor Yang (2014) and the use to asbuilt sections of track in a tunnels. This was done by Pejic (2013) which demonstrated high noise error of the rail tracks in figure 2.15

Figure 2.15 Distorted geometry of scanned track
Pejic (2013)

2.8 Data processing and analysis

A rigid body transformation of points from object space to scanner space is adopted in this research . Laser scanner resection geometry is explained Litchi(2000). The transformation of scans into one coordinate system Lindenbergh (2005) used the Interactive Closest Point (ICP) method. Gordon et al. (2004) used 3D resection to locate a scanner in object space. The raw points were transformed (georefrenced) into object space using a six parameter, rigid-body transformation. Rashetyk (2006) self calibration of each scanner was done in MATLAB. He estimated the Helmet transformation parameters between scanner and external coordinates systems for all scans. The calibration parameters assumed were the same as STS which was zero error additive constant, collimation, horizontal axis error and vertical index error, in a parametric least square adjustments. Calibration parameters estimated in the self calibration, used the error model of a total station. Additional parameters were modelled empirically.

Bae & Litchi(2007) on site calibration using planar targets. A point based self-calibration method . He used the FARO880 . The Newton-Raphson solution method can be successfully utilised for point -based calibration. (Gottwald 2008) states the target error can be determined out of Helmert transformation (reference data versus scanning data). Kersten (2009) calculated a standard deviation of the station coordinates. A standards deviation of the reference points was also calculated. The final measurement precision is really governed by algorithms for the fitting of the targets and extracting the centres. Scanners also show significant deviations if the angle of incidence is more than 45°. The spot size in relation to the angle of incident is also has an effect of measurement accuracy. Soudarissanane (2009) has coordinate conversions listed in his study. Abbas (2013) has all the equations. Dos Santos (2013) calculated the rotations first and then translations and scale factor. instead of using targets he used the vertical line of internal walls. Garcia(2013) investigated calibration modelling.

2.9 Conclusion

The engineering skills necessary to design laser scanners is very demanding and impressive. This chapter explained the technology in terms of measurement for all the instrumentation used in this research. A literature review was also conducted starting from 1998 and focusing in areas that have an impact in the calibration of TLS. Within the railway environment a small number of research work had been done which further justifies the need and funding of this research project.

Chapter Three - Methodology

3.1 Introduction

The project design, field work, data collection and analysis procedures for calibrating a Terrestrial Laser Scanner, will now be discussed. These procedures have been developed from the literature review in Chapter 2. The complexity of the project work, and limited availability of critical resources meant that the project transitioned through twenty two phases, these phases are mapped on a work flowchart Figure 3.1. This chapter will now explain each one.

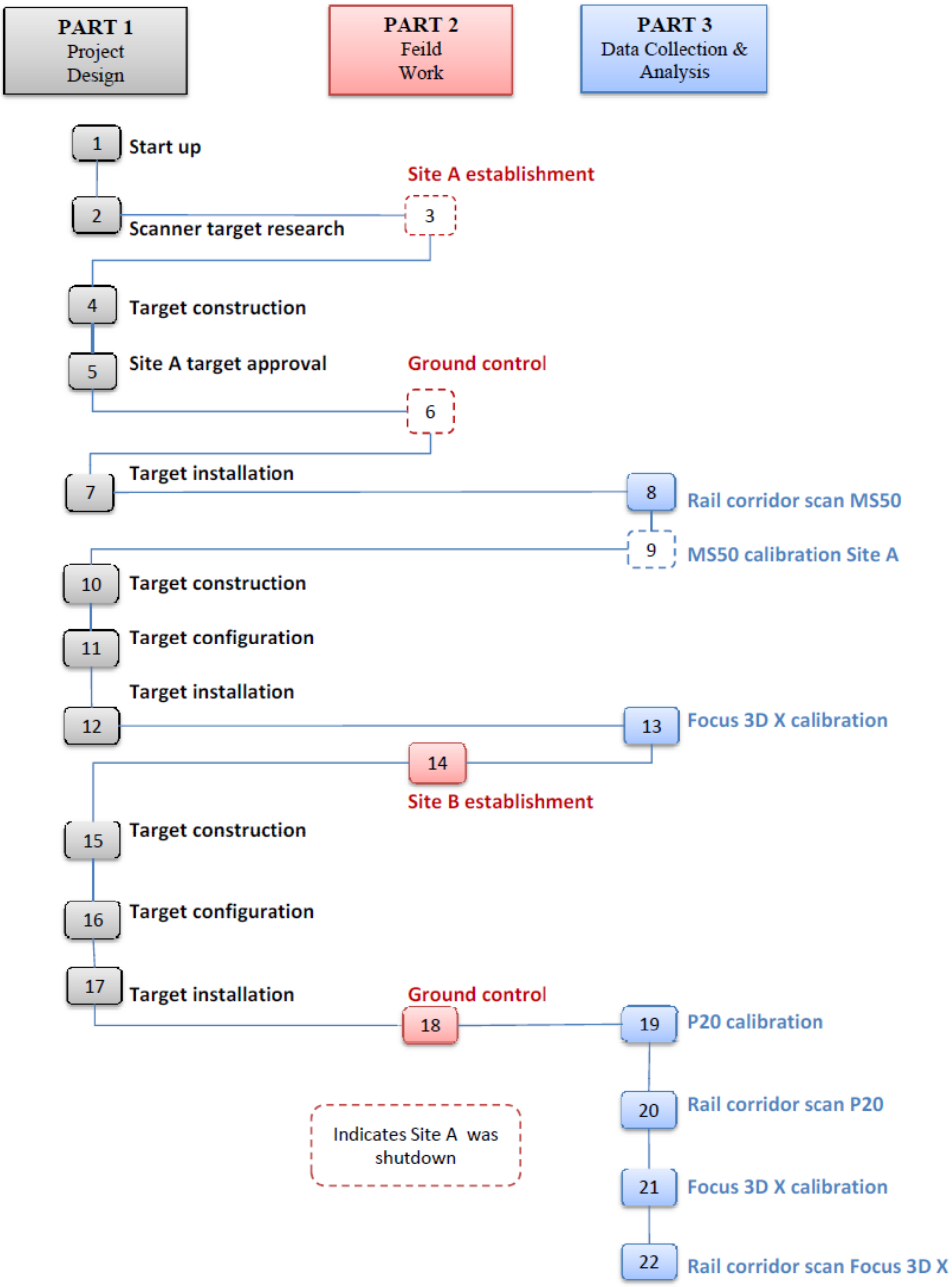


Figure 3.1 The project work flow

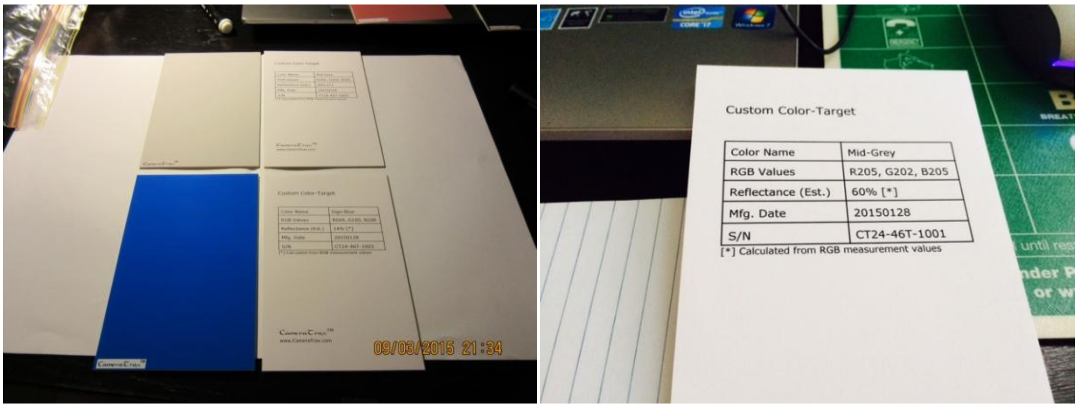
3.2 Project Design Stage 1

3.2.1 Start Up

Involved the initiation of consultation and meetings with Supervisor, USQ Library, Scanner Companies and Sydney Trains management to introduce my research project ideas. This was the most critical phase of this research project.

3.2.2 Scanner Target Research

This phase developed the concept of replicating the rail corridor environment, tones and material onto custom targets to test if indeed the rail environment can be scanned. During the Association of Public Authority Surveyors NSW (APAS) 2014 Conference, a paper on a method for Testing Reflectorless EDM (Evans 2014) was presented. This method used a Grey Kodak Card. After reading this paper the idea of constructing my own targets using Kodak cards of different tones was initiated to test the reflective energy of certain material Berenyi (2010) & Harvey (2002) in the rail corridor. These targets would then be used to calibrate the instrument . Sourcing Kodak cards was not easy as they are no longer manufactured in Australia. The optimal dimension of a scanning target had been determined by Reshetyk (2005) and was 14cm (Reshetyk et. al 2005). Photographic stores could supply grey, white and black photographic cards but they were not Kodak and were very expensive. The cards used for this research were sourced in America and were custom made from Camera Trax. This company produced the tones required and printed the reflectance percentage in the back of each card Figure 3.2. This would be important when it came time for measurements. The final dimension of the custom cards was 100mm x 150mm, which was governed by the price.



Custom Color-Target

Color Name	Mid-Grey
RGB Values	R205, G202, B205
Reflectance (Est.)	60% [*]
Mfg. Date	20150128
S/N	CT24-46T-1001

[*] Calculated from RGB measurement values

Figure 3.2 Custom reflectance cards

During this phase it is important to remember some of these cards will need to be setup on a Survey tripod and centred over existing ground control marks during scanning to connect to Sydney Trains coordinate system. For this research I wanted to use equipment that I had access too, hence the Leica prisms and holders. They were also chosen because they are fitted with target plates Figure 3.3, that can be used for locating the centre of a planar target when signalising and scanning them. Signalising targets means measuring to them directly using a STS. Using target plates is essential so when the instrument is setup in different positions and sighting to fixed planar targets you are confident you are measuring at exactly the same spot.

Figure 3.3 Leica Target Plate GZT4
(Sourced from Leica geosystems)

Accuracy specification for the two STS to be used is shown in Table 3.1.

Table 3.1 Leica Survey Total Specification
(Source Leica Geosystems)

Survey Total Station	Distance Measurement (any Surface) Accuracy
Leica TS15 & TS30	2mm + 2ppm

Surveyors in general have access to prism holders from there traversing equipment. By constructing scanning targets able to be easily fitted in existing prism holders is very efficient. The problem was the manufactures design distance from face of glass to the centre mark was unknown. Leica have only ever supplied the end user with the distance from centre to the back of the prism as shown in the image on the left (a) in figure 3.4. The image on the right (b) shows the characteristics of the prism constant being zero.

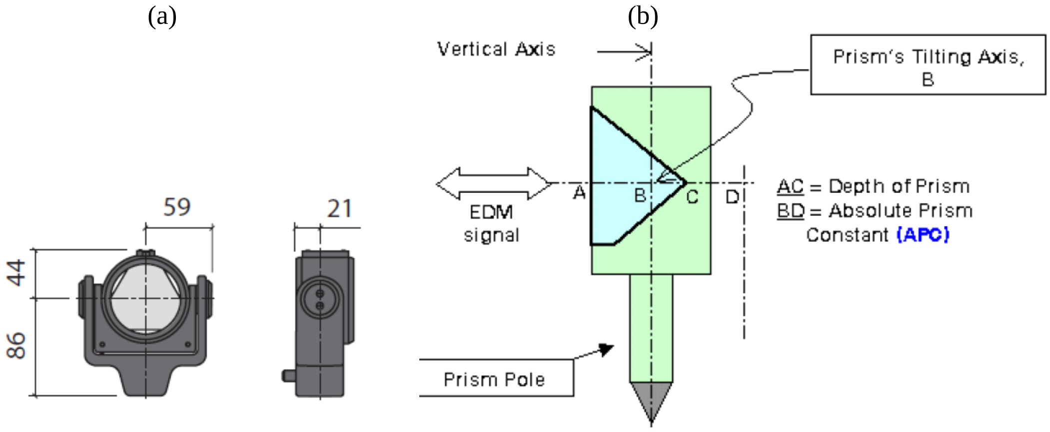


Figure 3.4 Leica prism assembly
(Sourced from Leica geosystesm)

An electric drill was used to drill holes along the existing curved zero centre line of the Leica GPH1 prim holder. The housing was extremely strong, drilling was not easy. For this research the decision was made to simple mark up the zero centre Figure 3.5 on the plastic housing and cut through to allow the cards to be installed on the face of the cutting edge.

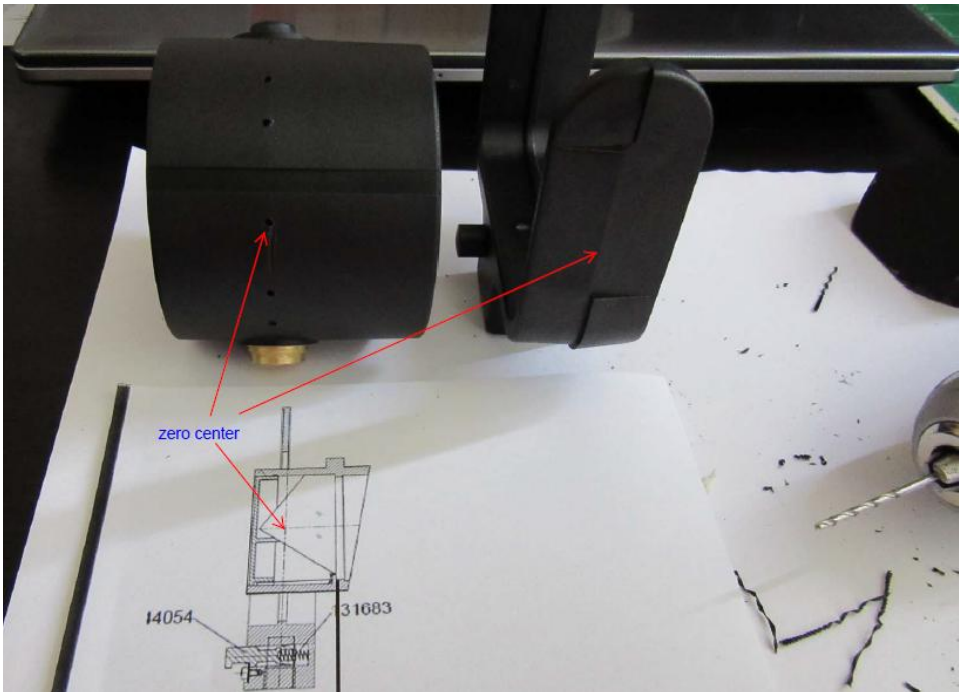


Figure 3.5 Deconstructed Leica GPH1 prism holder assembly to find the centre zero

Once the centre was marked a Proxxon draemel Figure 3.6 was used to cut through the prism holder housing.

Figure 3.6 Proxxon Draemel

The plastic was so hard, one cutting disk had to used per holder. At this point in time the total number of targets to be used was not clear Abbas (2014). For one prototype the excersie was justified. For many this was a very expensive exercise not feasible . The cost for only one modified assembly would be $275. Figure 3.7 shows the holder in its original form (a) and after cutting (b).


(a)

(b)

Figure 3.7 Leica GPH1 prism holder

C R Kennedy the Leica distributor in Australia was approached and contacted Leica Geosystems to obtain the design distance required for this research. It was given and shown in Figure 3.8.

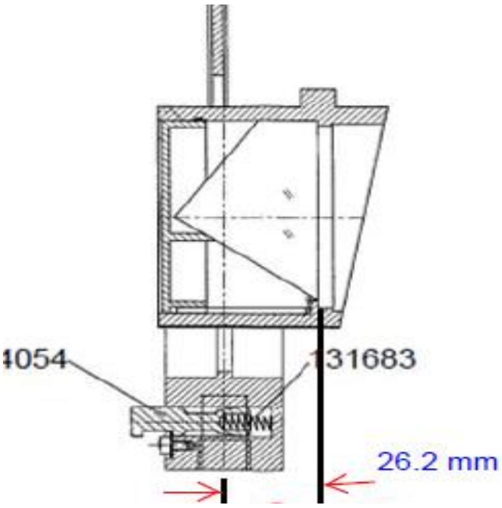


Figure 3.8 Leica distance from the glass front of prism to the prism centre.
(Sourced from Leica geosystesm)

You will need to point to the centre of the prism to avoid any tilt error from the prism holder when measuring to the position of the face of the glass prism and this is why target plates were a good idea. The option to purchase precise prisms, that can be locked into to certain tilt angles was not feasible for this research.

Due to the fact the accuracy of the laser scanner measurement is depended on the energy return of the surface being measured, three different material prisms were made for testing, that represented rail corridor material. A 3D printer was used to produce three glass prism shapes made of sandstone, metal and plastic. Figure 3.9 shows the transition of the Leica glass form prism (a), to the 3D model generated by the 3D printer (b). The images (c) & (d) represent the final products, a sandstone and a metal prism.

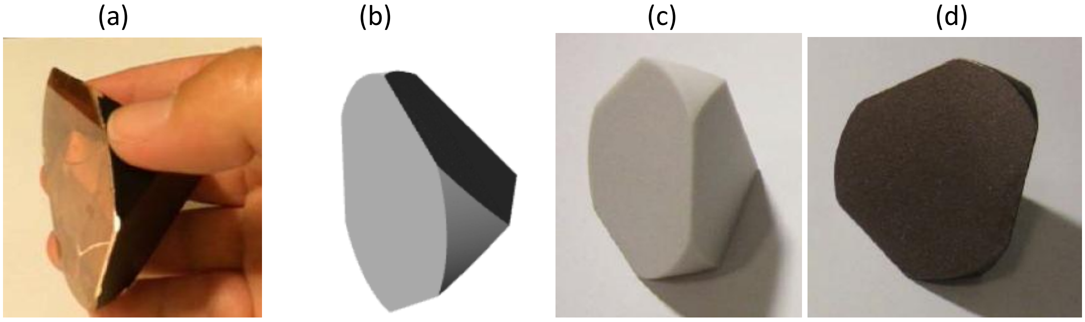


Figure 3.9 The transformation of a glass prism.

3.3 Field Work 1 Stage 2

3.3.1 Site A establishment

Visits to prospect sites for assessment of suitability for Scanner calibration were done. The prerequisites for this site were:

- a large size that will allow set up of many targets to allow a large number of redundancies during analysis to get good results and various horizontal and vertical angles and range (distance).
- An indoor site that has solid internal walls or framework with good indoor lighting
- Stable floor to assist with the measuring
- Access to all internal walls, floor and possible ceiling (if safe and easy to access).

Sydney Trains warehouse Figure 3.10 available to use with access times restriction but at no cost was chosen.


Figure 3.10 Sydney Trains warehouse in Auburn NSW (site A)

3.4 Project Design Stage 3

3.4.1 Target Construction

All the items sourced during the research will now be used to construct more targets. The first task was to install the tone cards in the prism holders. This process involved cutting the shape of the glass prism out of the cards as shown in Figure 3.11

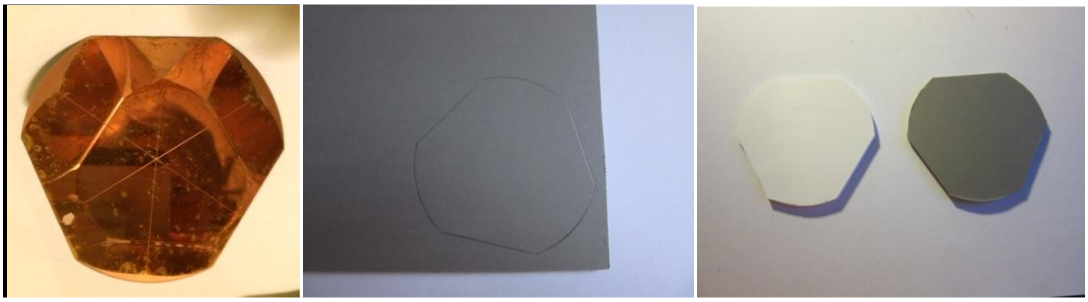


Figure 3.11 Cutting out prism shapes from custom cards

The next task was to install the cut outs in the holder Figure 3.12 . Foam was the key element that would hold the card in place once the prism holder was assembled .

15/03/2015 16:11

15/03/2015 16:19

15/03/2015 16:17

Figure 3.12 Installation of prism card

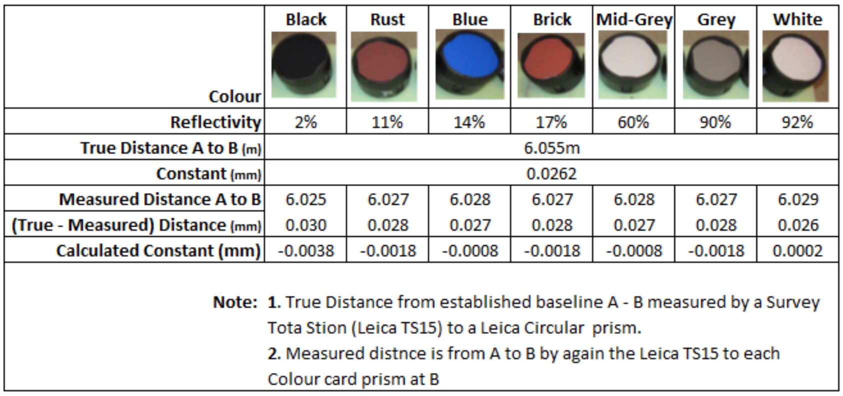
In Figure 3.13 you can see all the individual elements and the final product

15/03/2015 16:19

Figure 3.13 Close up of the card placement and final product.

Once all the cards were installed , the reflectivity and prism constant must be tested to check the accuracy of the assembly. This was done on a small baseline due to time constraints. The Leica TS15 STS was setup, constant set to zero (circular Prim) and a distance was measure to a glass prism being 6.055m. Then the prism mode changed to (reflectorless) prism constant 34.4mm and all the cards and material prisms were measured. The results are shown in Table 3.2.

Table 3.2 Reflective card testing results

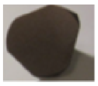


	Black	Rust	Blue	Brick	Mid-Grey	Grey	White
Colour							
Reflectivity	2%	11%	14%	17%	60%	90%	92%
True Distance A to B (m)	6.055m						
Constant (mm)	0.0262						
Measured Distance A to B	6.025	6.027	6.028	6.027	6.028	6.027	6.029
(True - Measured) Distance (mm)	0.030	0.028	0.027	0.028	0.027	0.028	0.026
Calculated Constant (mm)	-0.0038	-0.0018	-0.0008	-0.0018	-0.0008	-0.0018	0.0002

Note: **1.** True Distance from established baseline A - B measured by a Survey Tota Stion (Leica TS15) to a Leica Circular prism.
2. Measured distnce is from A to B by again the Leica TS15 to each Colour card prism at B

The metal, galvanised painted plastic and sandstone prisms were all measured. the results are shown in Table 3.3

Table 3.3 Reflective material testing results

	Sandstone	**Galvanised painted Plastic**	**Metal**
Colour			
Reflectivity	Unknown	Unknown	Unknown
True Distance A to B (m)	6.055m		
True Constant (mm)	0.0262		
Measured Distance A to B	6.031	6.028	6.027
(True - Measured) Distance (mm)	0.024	0.027	0.028
Calculated Constant (mm)	0.0022	-0.0008	-0.0002

Note: **1.** True Distance from established baseline A - B measured by a Survey Tota Stion (Leica TS15) to a Leica Circular prism.
2. Measured distnce is from A to B by again the Leica TS15 to each material prism at B

One of the aims of this research is to test if existing survey marks - Track Control Marks (TCM's) located in the rail corridor Figure 3.14 (a), can be scanned. So the next step was to design another series of custom cards fitted with a Steel Survey Pin (SSP). The steel pin is very small, only 5mm in diameter as shown in Figure 3.14 (b).

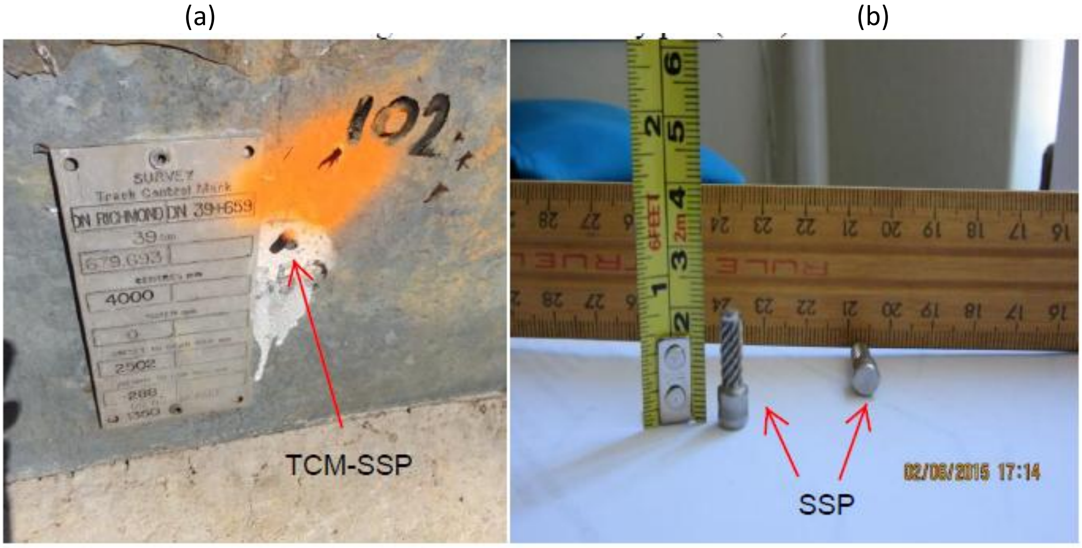


Figure 3.14 A TCM and SSP

The centre was measured and marked on a template. A hole was drilled through the template and an SSP was fitted Figure 3.15.

Figure 3.15 Cards fitted with SSP

The next task was to construct posts for the prism holders to be fitted into. The posts would be installed in the scanner calibration space Site A, and the target plates fitted on them. This would make a very sturdy target to sight too for calibration measurements.

At this stage of the research an indoor calibration space had been found. It was a large size (11m x 10m x 5m) with solid floor and walls and a good variance of angle and distance to establish a network of targets figure 3.16.

Figure 3.16 Site A

The design of the posts had to take into consideration the form of the steel frame in Site A. Timber was used for the base and aluminium rods cut to required length for the prism holder to slide into figure 3.17.

Figure 3.17 Post construction

Once the prism holder was fitted it had to clear the frame as shown in Figure 3.18.

Figure 3.18 Complete target in posts.

19 prism holder targets were installed in Site A. The posts and wooden block apparatus had to be thought of on the spot as it was not acceptable to install any items that would abstract a forklift getting pallets in and out of the frames. Araldite was used to fix the posts on the steel frames inside Site A.

More targets were continually being constructed to fill Site A and still keep within project objectives of trying to replicate materials, tones and colours found in the rail corridor see Figure 3.19.

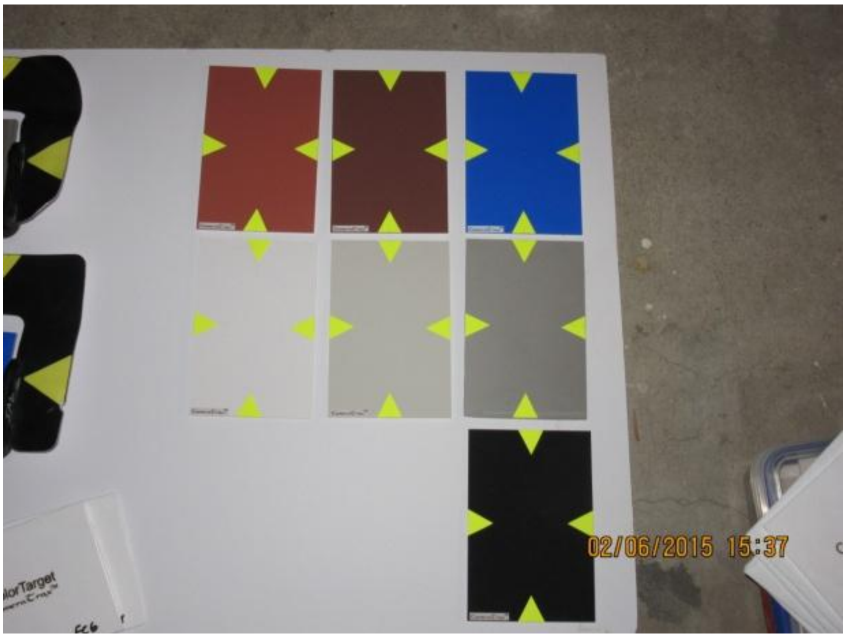


Figure 3.19 Custom card with sights

Scanner manufacturer targets were also replicated Figure 3.20 (a), custom cards were also installed on the actually zero centre of the prism yoke (b) & (c).


(a) (b) (c)

Figure 3.20 Scanner Targets constructed

3.4.2 Site A Target Approval

Completed a site A induction refer to Appendix B. Temporary paper targets had to be installed at desired location in the warehouse for safety inspection and approval from warehouse manager. The purpose of the approval was to demonstrate the targets will not obstruct forklift traffic in the warehouse refer to figure 3.21.

Figure 3.21 Approved Temporary photocopy Target

3.5 Field Work Stage 4

3.5.1 Ground control

Ground control was placed inside the warehouse, on the concrete floor as demonstrated in Figure 3.22.

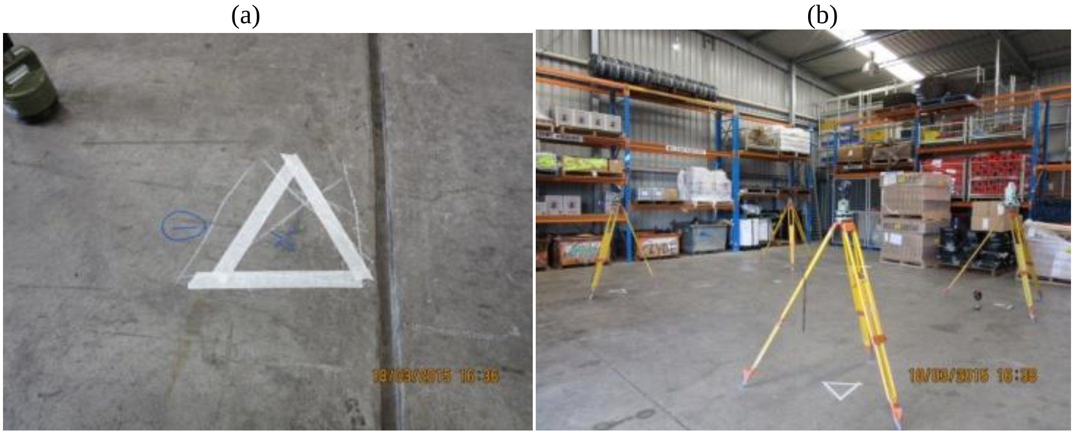


Figure 3.22 Establishing ground control

Once the four traverse stations were marked on the ground, they were measured. The final coordinates of the ground control were determined by the following process:

- Six round of angles were measured to each station
- The raw GSI file was reduced using CompRail / CompNet Least square software which produced final coordinates
- All stations were levelled using the Leica DNA3000 digital level

3.6 Project Design Stage 5

3.6.1 Target Installation

Prior to installation a target layout configuration had to be designed. This research is to calibrate a TLS. To do this the targets had to cover a wide range of vertical and horizontal angles, to really test the instrument capabilities. A network of targets was designed Reshetyuk (2005) by drawing the layout of the warehouse shelving bays and placing miniature paper targets in various location until a reasonable even spread of all the various targets achieved optimal configuration. Refer to Figure 3.23.

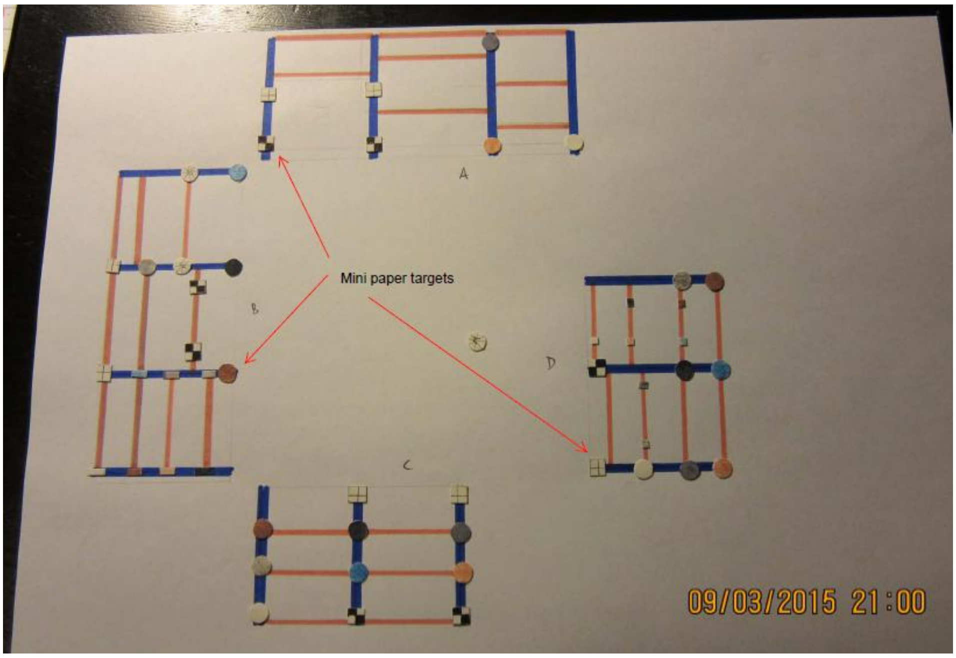


Figure 3.23 Target configuration

19 complete Leica prism holders Figure 3.24 (a) with target plates were installed in the warehouse. This amount of targets required a coordinated effort from three survey regional office within Sydney Trains. The image on the right (b) is a complete prism assembly fitted with a tone card and SSP and inserted on the post.

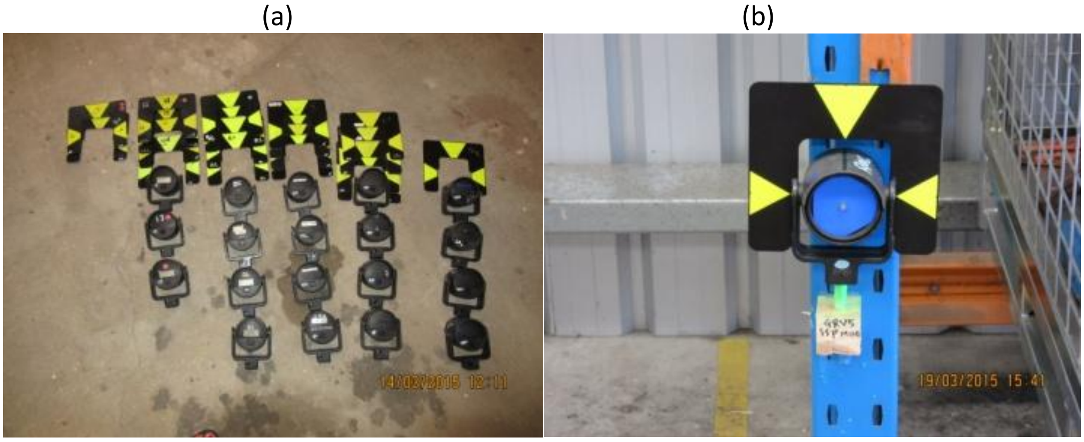


Figure 3.24 more targets

3.7 Data Collection & Analysis Stage 6

3.7.1 Rail corridor scan MS50

The Leica MS50 was sourced from Sydney Trains Hornsby regional office. The location for the rail corridor scan was the Sydney end of Penrith station at kilometrage 54+691 Figure 3.25. After a worksite protection plan was in place, three backsights were setup on existing ground control. The MS 50 was setup in a safe place and its position was coordinated via resection from the three known backsights. The MS50 was now ready to scan.

Figure 3.25 Section of Rail track (Main West)

The area of track selected was within a 70m range from the scanner position, having dimension (100m x 120m x 8m) refer to Figure 3.26

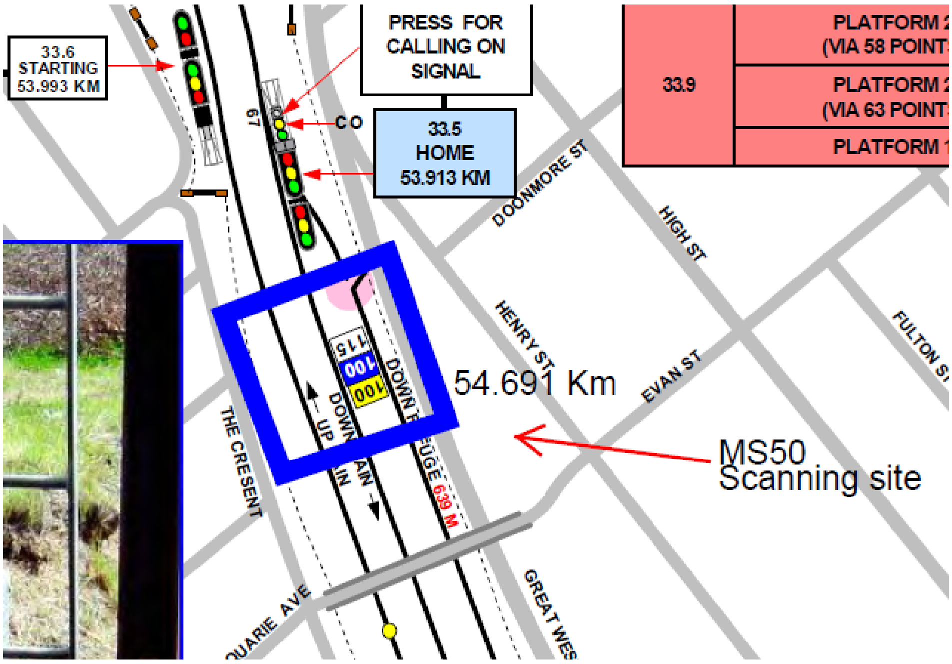


Figure 3.26 Map of Rail track (Main West)
(Sourced from RailSafe)

The instrument specified scanning range is 300m with range noise 1.0mm at 50m Leica Geosystems (2013). This research aims to test the scanning response to SSP's, having a diameter of 5mm. This diameter set the required spacing resolution for the MS50. This instrument was unable to scan the pre determined section of Railway track in the field to the point spacing required . One good feature of this instrument was that once the area limits of the proposed scan were calculated, the instrument displayed the scan time required to measure the scene in the chosen resolution.

Unfortunately the time required to scan this scene was not productive and the decision was made in the field not to proceed. The scan times in relation to the point cloud spacing options are shown in Table 3.4

Table 3.4: Scan time for a scan area of Rail Portal Spacing

Point Cloud Spacing	Time required for scan
1mm to 1mm	520 hrs 36 min 14 sec
5mm to 5mm	22 hrs 20 min 44 sec
10mm to 10mm	6 hrs 7 min 25 sec
20mm to 20mm	1 hr 51 min 5 sec

3.7.2 MS50 calibration site A

The Leica MS50 was also taken to the calibration warehouse facility to scan the targets as seen in Figure 3.27.

Figure 3.27 Western targets wall of warehouse

Figure 3.28 Shows a close up of one of the targets from a ground station position (a) and (b) is the same target imaged on the leica MS50.


(a) (b)

Figure 3.28 Top left corner target

Once again the time to scan just one wall with dimension (5m x 3.5m) was too long and the file produced would not be manageable. The scan times in relation to the point cloud spacing options are shown in Table 3.5. Sixteen photos were taken by the instrument in approx 1 min to cover this scene. Even though the testing was unsuccessful it was good that this was discovered in the early stages of the project. This instrument will no longer be used in the project

Table 3.5 Scan time for a scan area of approx 5m x 5m.

Point Cloud Spacing	Time required for scan
1mm to 1mm	7 hrs 11 min 46 sec
5mm to 5mm	24 min 10 sec
10mm to 10mm	9 min 9 sec
20mm to 20mm	4 min 39 sec

3.8 Project Design Stage 7

3.8.1 Target construction

This phase involved solving a resource issue. The complete prism sets being used are no longer available. The problem was solved by constructing similar type targets for replacement. Figure 3.29 shows the new targets. The custom cards in the prism holders were take out and stuck on a 10mm thick foam board. The target plates were printed on cardboard and also stuck on the foam board aligned with the prism shape card (a). These targets were then simply velkroed onto the existing timber blocks. Image (b) shows the cardboard target plates attached to the zero offset card fitted on the center of the yoke assembly and supported by a paddle pop stick for flatness support.

Figure 3.29 Foam targets and cardboard target plates

To minimise waste of costly resources, all the custom card cut-offs were resized and made into various shape targets with SSP's. This was a good idea as it would test how the SSP's would be scanned with various tones and size reflective surface background Figure 3.30.

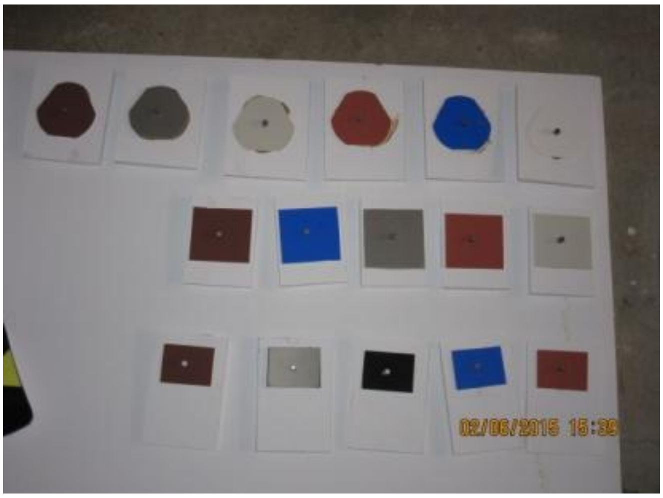


Figure 3.30 Off cut targets

3.8.2 Target configuration

The miniature target strategy adopted previously in this work was used again Figure 3.31. There was a total of 206 targets to be installed for Site A. The mapping of all miniature targets on a pin board prior to installation resulted to a balanced testing of all the targets. The type of targets and there tones determine their position as this layout is still representing a Rail corridor environment. For example the targets fitted with SSP's are positioned the same height above ground as they would be found in the Rail corridor, 300mm above the low rail Sydney Trains TMC 202 (2012) .

Figure 3.31 Miniature targets

The mini targets were glued on pins and placed at a specific location on A3 size photos of Site A's four walls, on a cork board as in Figure 3.32. Retro targets also installed.

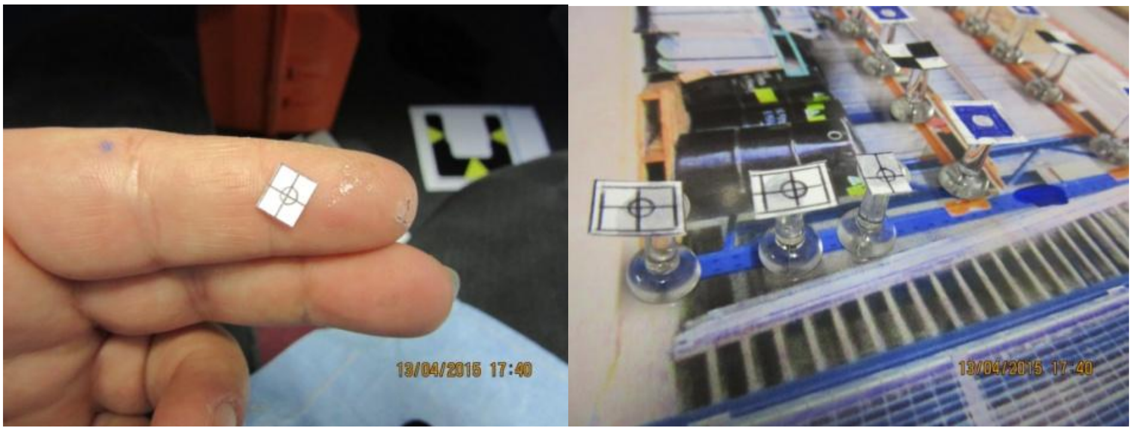


Figure 3.32 Target pins

3.8.3 Target installation

All targets were installed. To easily identify each target during data analysis of the scan, each target will be given a unique number in the form of a label next to the target.

In Figure 3.33 (a) you can see the targets installed on the Northern wall of Site A, and (b) is the top right corner of this wall, showing target and numbering install.

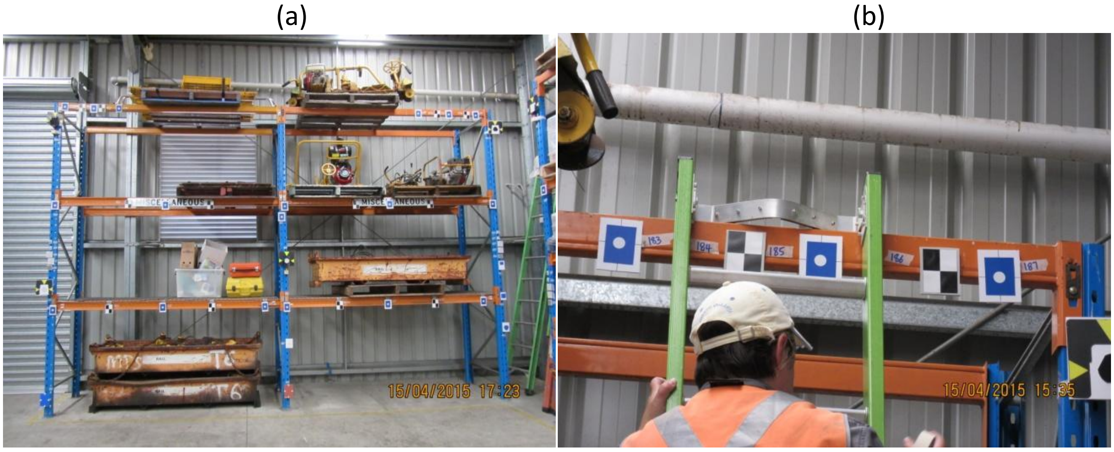

(a)
(b)

Figure 3.33 Target install

3.9 Data Collection & Analysis Stage 8

3.9.1 Faro Focus 3D X330 calibration

Scanning of all targets from a minimum of five scan positions with the Faro was completed in 15minutes , set at its highest resolution with mid range quality delivering a point distance of 3.068mm at 10m. The height of the scanner above ground was changed from each position as recommended in Soudarissanane & Lindenbergh & Menenti & Teunissen (2009) , and five scan positions provided a good number of redundancies Garcia (2013). The point cloud captured by this scanner is shown in Figure 3.34.

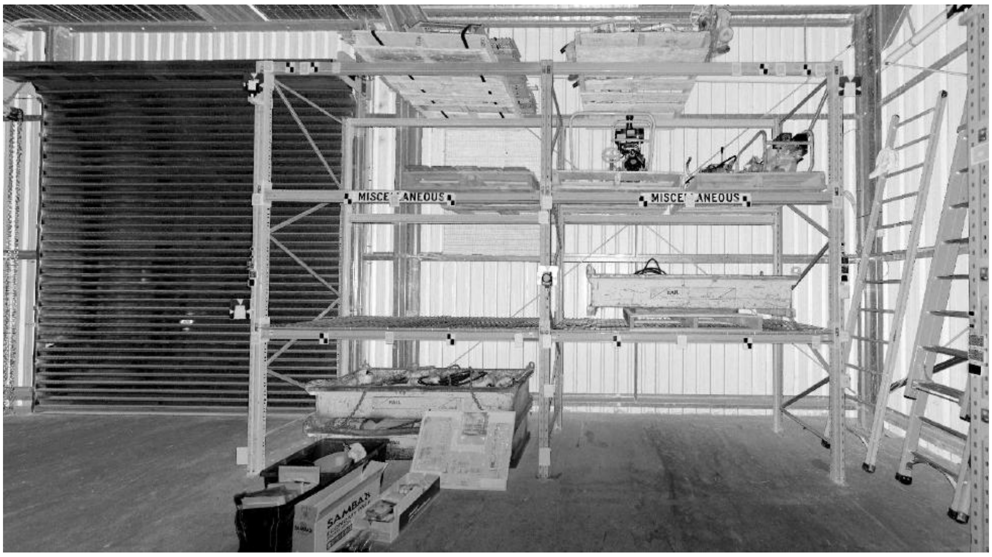


Figure 3.34 Northern wall of Site A point cloud form faro Scene

On the same day measurements of all targets with the TS15 was done from two ground control marks to allow for comparison of STS and TLS target X, Y, Z positions. This was an extremely time consuming exercise which took approximately four hours.

At this point in time of the Project work the indoor warehouse site for calibration had to be vacated without notice, and all targets and posts removed permanently due to management unforeseen activities that required the indoor facility to be vacated unexpectedly.

All of the phases of the project work in terms of the field work and data collected so far satisfy 80% of the research. A great deal has been learnt and constructed up to now and a great deal of interest from the Scanner manufactures has been generated. To end the project field work at this time, reporting the findings of only one scanner would not be acceptable. Due to the enormous amount of time invested to come so close to the phase of using a second scanner and be asked to relocate is disappointing.

A new calibration site is sourced and targets will be re-installed. The analysis will have better results and value in the Surveying profession if two different brand of Scanners were compared. For this comparison to be done both scanners need to be tested exactly the same way. It is important to note the second facility is a much smaller space but still an acceptable size (9m x 4m x 3m) to complete this work, as recommended by Litchi (2013) & Banson (2014).

3.10 Field Work Stage 9

3.10.1 Site B establishment

Site B Figure 3.35 has been located at a cost, this will provide exclusive access for one month. Refer to Appendix H for the Project Costings.


19/06/2015 13:54
19/06/2015 13:55

Figure 3.35 Site B

There were two restriction on the walls of Site B. In figure 3.36 (a) the wall panels had grooves of approximately 120mm in width, in (b) some of the panelling stepped in by 10mm which could cause a shadowing effect on some of the targets. This will require a backboard of certain size to be installed on the panels with the pattern targets glued on the boards.


(a)
(b)

19/06/2015 15:08
19/06/2015 15:08

Figure 3.36 Site B indoor panelling issues

3.11 Project Design Stage 10

3.11.1 Target construction

The scans taken with the Faro at Site A, were processed to view the point cloud to test if there were any issues with the targets Figure 3.37. Unfortunately at this point in time it was discovered that scanners do not recognise end user self made targets. This was a significant discovery to this research.

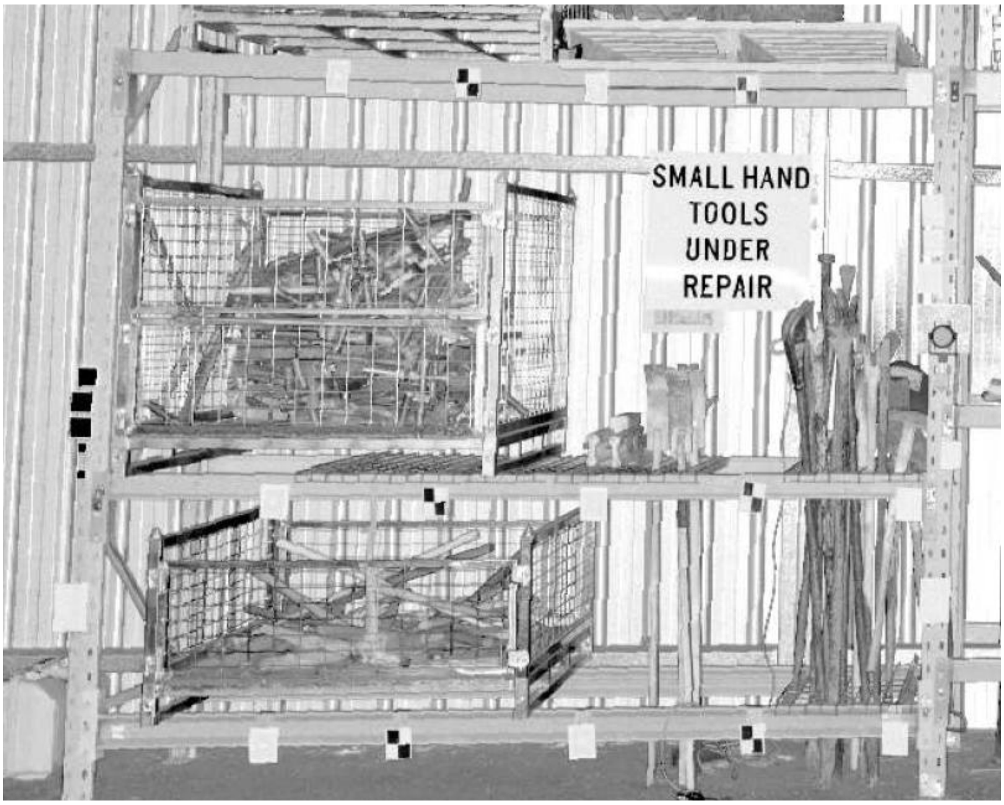


Figure 3.37 Scanned custom targets point cloud from FARO Scene

This means the Faro scanning software Scene 5.50, is not able to automatically extract the centre of all the targets that were scanned. If the centre of targets is needed for this research it will have to be extracted manually by zooming right into the image . This is unacceptable, as the aim of this research is defining accuracy. The Leica P20 scanning software Cyclone 9.0 is also unable to extract the centres of all my targets, for the same reason.

The reason for this issue provided by both manufactures was algorithms. Scanning software can only automatically extract for the end user, the centres of manufacture supplied Black & White checker pattern targets shown in figure 3.38 only. The scanner scans the targets pattern and the algorithm is recognised by the software to extract its centre.

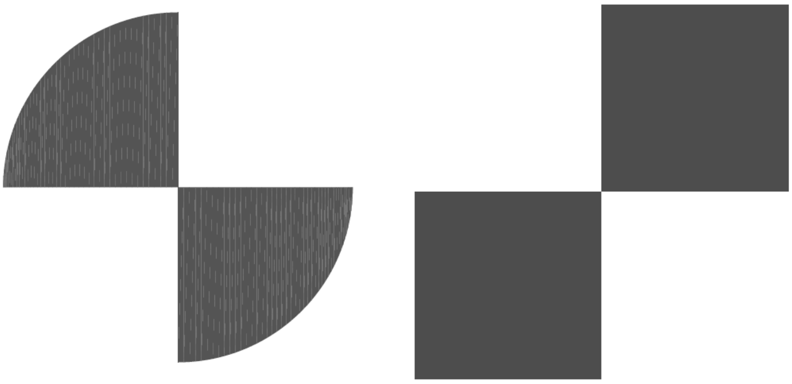


Figure 3.38 The Leica (round) and faro Scanning Targets.
(Sourced from Leica Geosystems and Faro Technology)

To overcome this issue the solution was to print the manufactures targets on a laser printer, construct a solid backboard to glue the targets onto and install them in Site B see Figure 3.39.

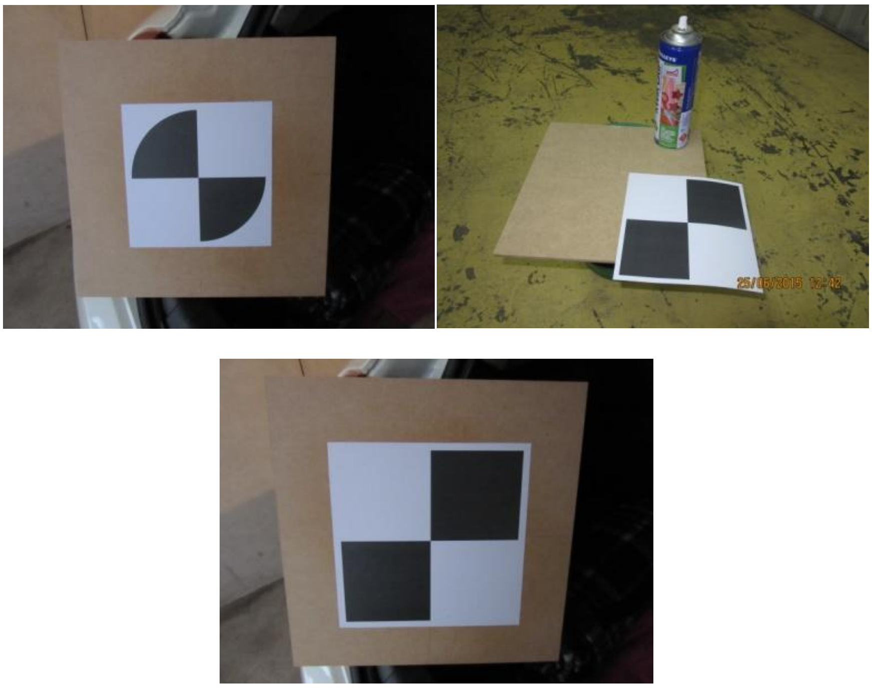


Figure3.39 Sticking the paper targets on MDF boards.

This will not allow me to test the reflectivity responses of rail corridor material during calibration. The only issue left was the testing of the SSP's. The solution was to install the SSP through the centre of the manufacture's pattern target. The methodology will be the SSP is too small to effect the patterns algorithmic recognition. The manufactures could not guarantee this would work and had to be tested as part of this research project. The SSP installation process was as follows:

- Cut to size a piece of timber of 25mm thickness (the length of the SSP is 19mm).
- The boards had to take into account the panel non flat irregularity and the size of the targets.
- Drill a hole of 5mm diameter in the centre of the board and tap the SSP through the hole as shown in figure 3.40, with a bit of araldite on it to fit in place and flash on the board.
- A hole was punched through the centre of the paper pattern targets and carefully centred on the nail and glued as seen in Figure 3.41.

Figure 3.40 Installation of SSP on timber board

Figure 3.41 Target over SSP

At this stage of the project the literature review had not discovered any research indicating a flash surface will scan best without any objects protruding from its surface. The scanning of edges were not desirable but looking at the size of the SSP having it flash will eliminate noise around the pin edge - this means more accurate measurement without shadowing effects from the pin protruding from the board. All that was required now was the amount of targets that were needed to establish an optimal network for the self calibration of a TLS.

3.11.2 Target configuration

In Site B the targets can be placed anywhere, this means placement configuration needs to be decided prior to target installation. Two scanners were going to be calibrated in Site B, this means there were two scanning target types that had to be used, a Leica and a Faro. Of course there were no guarantees that one brand scanner would recognise the algorithmic pattern of the other as the size of the targets were slightly different in there dimensions and shape- this had to be tested. With this in mind and tight time frames, I decided to mix the patterns in my target network equally. By this I mean the installation would have a pair of the same targets at various locations and aligned in the horizontal and vertical direction using a line laser, the BOSCH Quigo figure 3.42.

Figure 3.42 - The BOSCH Quigo in use

The following target network configuration was designed and shown in Figure 3.43. All the targets on the bottom of each wall have been fitted with an SSP. They are simulating approximately the 300 millimetres above ground scenario, which would occur in the rail corridor. Instead of ground it would be of the low rail of the track in the rail corriodr.

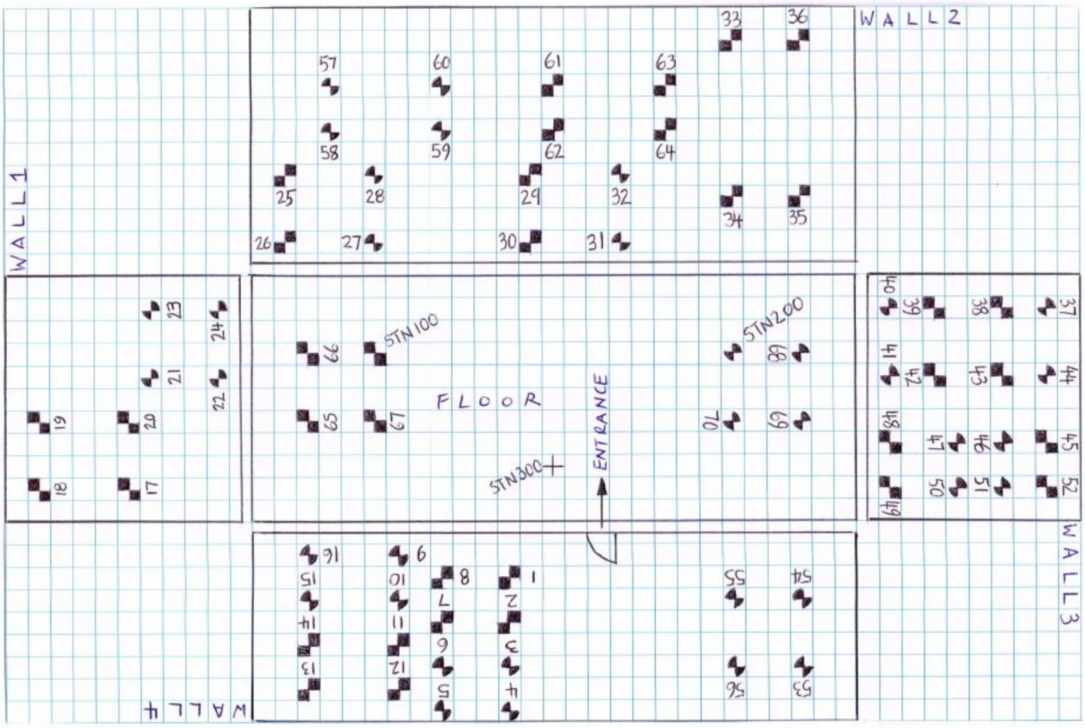


Figure3.43 A sketch of the target network configuration

The idea of having the pattern targets paired was to allow for a direct measurement with a tape, between them. I wanted to do a comparison of direct measured joins and the calculated joins from the coordinates of the targets after point cloud registration.

3.11.3 Target installation

Target installation was based on the target network layout . In Figure 3.44 the target installation process is seen. At first (a) white dot stickers were used for the marking of the approximate positions of each target. The next step used the Quigo laser to align the dots. Verkro strips were used to attach the boards on the wall panels (c) shows the strips being placed around the dots. To maintain costs low and provide a very sturdy solution only three velkro strips were needed for each target. In (d) the paper targets were glued on the boards and numbered in the back of the boards. It is important to make it as is as possible to place the targets in the correct position the first time - this was a concept used at Site A and worked well. (e) shows the targets now installed on the wall in the correction positions all that is left now is to re-align the targets horizontally and vertically with the Quigo laser for the last time.

(a) (b)

(c) (d)

(e) (f)

Figure 3.44 Target Installation

It is important to mention at this point the orientation of the patterns was critical, the algorithms in the TLS software could introduce errors in the automatic target centring extraction process, if orientation was incorrect. The manufactures could not confirm if that would be the case but this chance could not be taken in this work so extra care was taken to make sure all 70 targets were orientated correctly as previously indicated. Figure 3.45 shows the incorrect orientation.

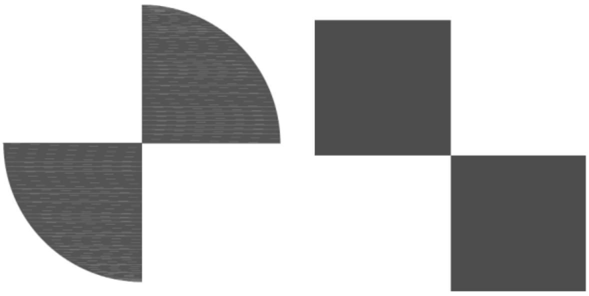


Figure 3.45 Incorrect orientation of scanner targets

3.12 Field Work Stage 11

3.12.1 Ground control

Three ground control marks were placed as shown in Figure 3.46. Site B is a smaller size so for this research it was decided a second total station the Leica TS30 is to be used to measure the ground control as an independent check.

Figure 3.46 Site B ground control stations

3.13 Data Collection & Analysis Stage 12

3.13.1 P20 calibration

In this phase the scanning of the targets was done from three scan positions. Figure 3.47 shows the P20 at scan position 1 (near STN100).

Figure 3.47 P20 at scan position 1

The scanner height was varied from the ground at each scanner location. The spatial resolution was at 1mm at 30m. The point cloud from Station (STN) 100 with target centres already numbered and centres extracted and is shown in Figure 3.48. This point cloud has been zoomed in to highlight the enormous fine detail captured.

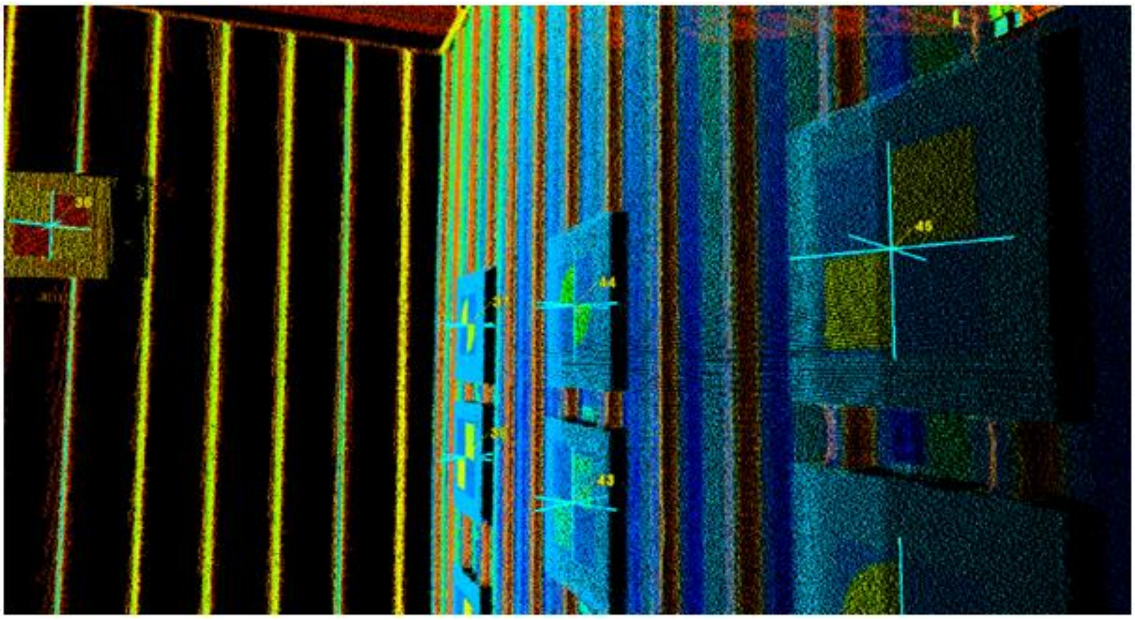


Figure 3.48 Point cloud from Cyclone 9.0 at STN100.

3.13.2 Rail corridor scan P20

The location of the rail corridor scan was at the country end of Redfern Station on the upside shown in Figure 3.49.

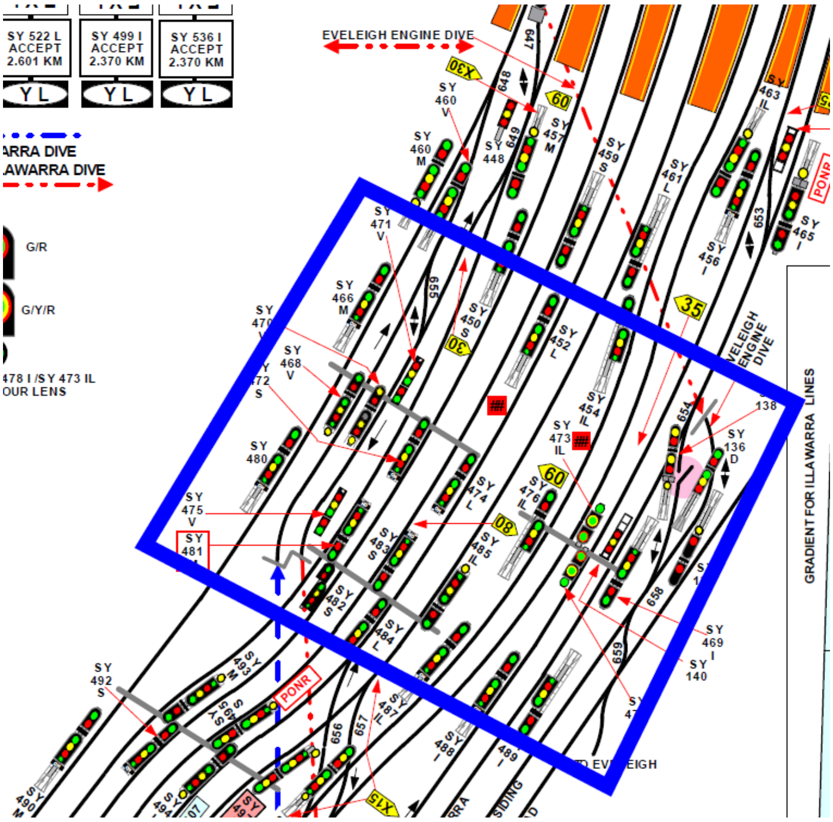


Figure 3.49 P20 rail corridor scan site
(sourced from Rail Safe)

The P20 was setup on a survey tripod levelled up, a new project was created , settings were set and the scanning began Figure 3.50.

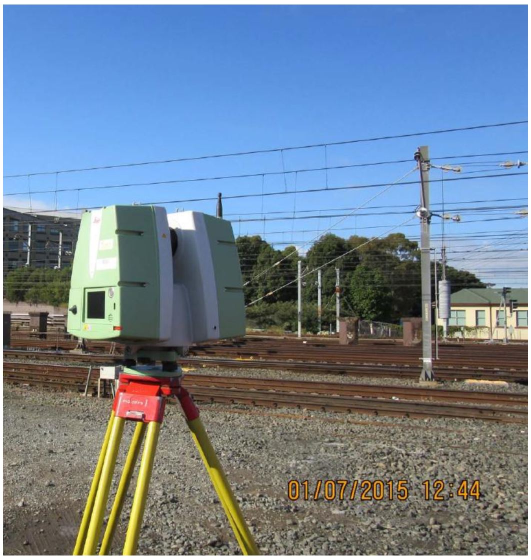


Figure 3.50 P20 in the rail corridor

Within this area three SSP's figure 3.51 were chosen to scan and use for registration. The image on the bottom was fitted with the incorrect orientation due to safety concerns and trains running approaching peak time this target could not be re-orientated. It will be interesting if this will cause an issue with the data during analysis.

Figure 3.51 The three SSP's - survey control with Leica Targets

The P20 has the ability to scan the control targets at a distance on site, in a super fine spatial resolution (1mm) and then scan the scene of the rail corridor at a different point resolution (10mm) accuracy. For this particular job foam backboards were used to glue the Leica scanner paper targets through the SSP, in a flash position. In this particular case, the back boards had to be modified to get around the metal TCM plaques that are fixed onto the face of the mast above the SSP. This situation highlighted the issue of the plaques Figure 3.52.

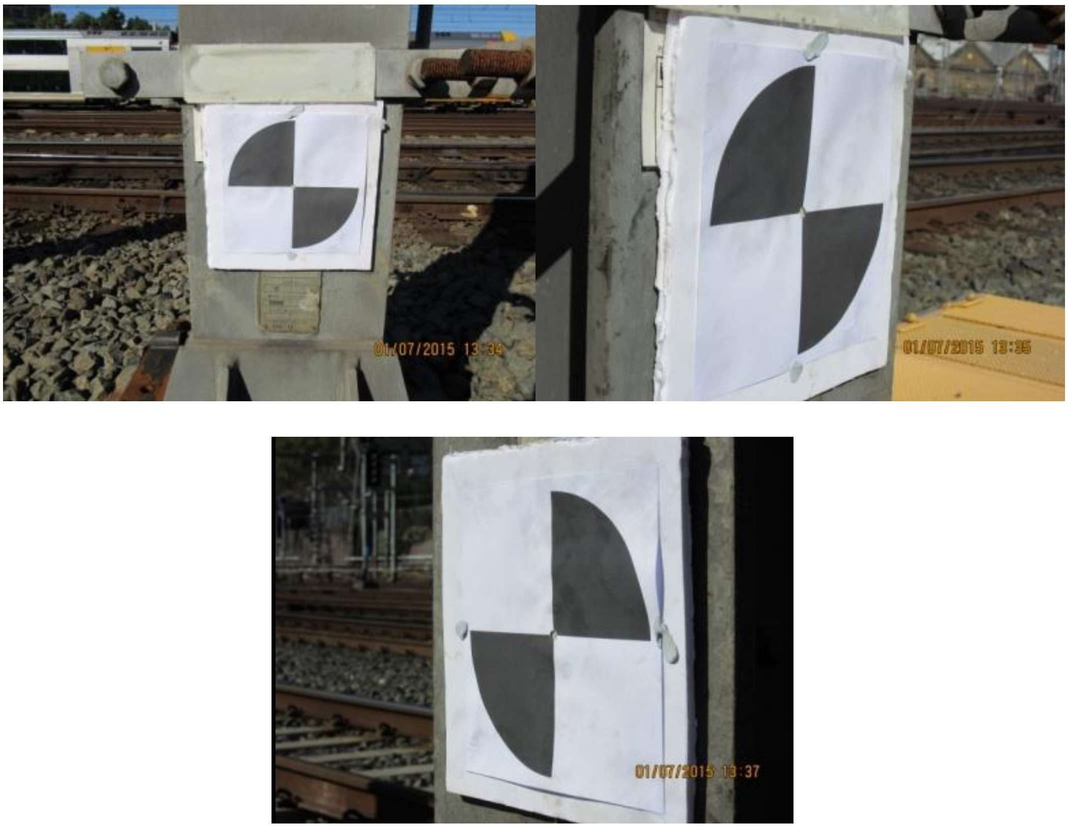


Figure 3.52 Plaque positions near the SSP's.

The TCM plaques are metal and permanently attached above all SSP's. The plaques show critical design data related the track Figure 3.53. They cannot be removed.

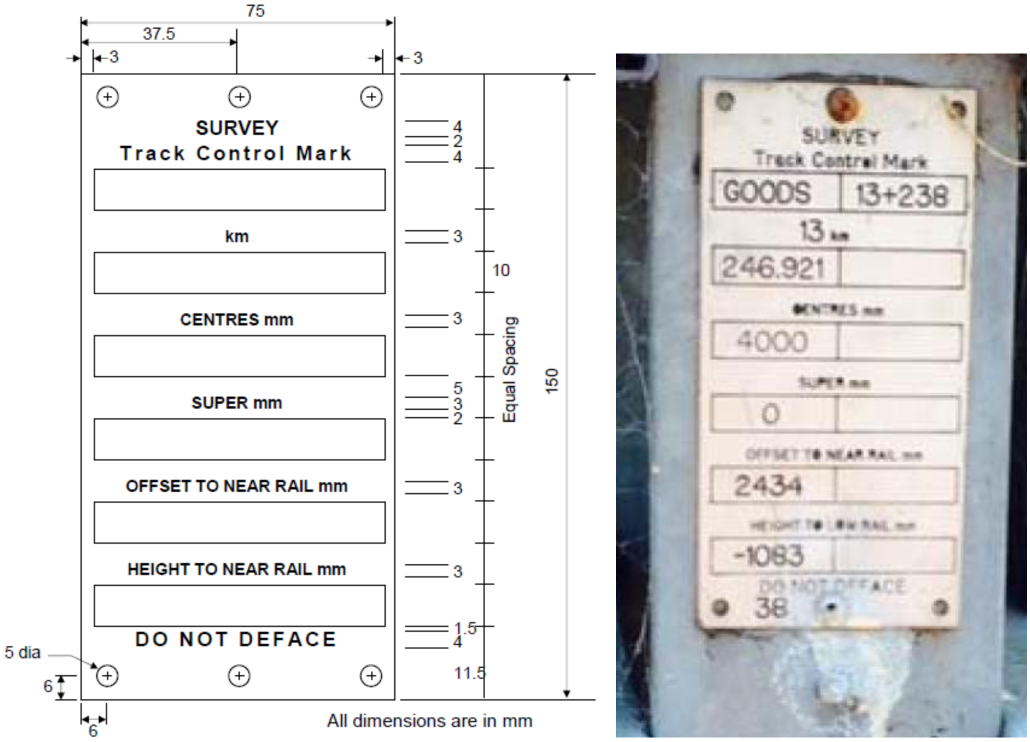


Figure 3.53 Specification for TCM
(source Sydney Trains TMC 212 Survey 2009)

A possible solution to working around the plaque obstruction, is to paint the pattern targets at a higher position along the face of the mast structure and along the rail corridor. You would not need to paint a target at every mast. Additional field work would be required to survey all the targets using STS and coordinate them to the Sydney Trains coordinate system. This idea would setup the rail corridor permanently for scanning. It would be time consuming but an efficient long term strategy to assist the implementation of new technology in the future. This work is outside the aims of this research paper but is worth further investigation in the future.

3.13.3 Faro Focus 3D X 330 calibration

The scanning of all the targets were also done from the same three scanner positions, with the Faro Focus 3D X 330 figure 3.54.

Figure 3.54 Focus 3DX at scan position 1

The scanner height was varied from the ground at each scanner location just like the Leica P20. The spatial resolution was at 1mm at 30m. The point cloud from Station (STN) 100 is shown in Figure 3.55

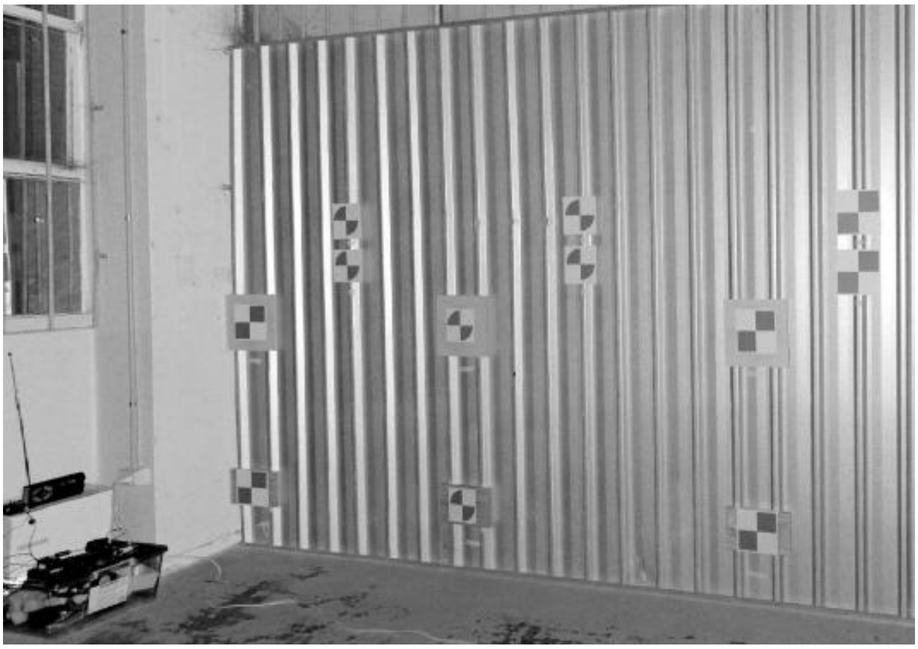


Figure 3.55 Point cloud from Faro Scene5.5 at STN100.

3.13.4 Rail corridor scan Faro Focus 3D X330

The Faro was also taken to Redfern and was step in the same position as the P20 figure 3.56

Figure 3.56 The Faro track scan at Redfern

The exact SSP's figure 3.57 were used with the Faro scanner as well, for registration and coordination of the scan point could. .

Figure 3.57 The three SSP's - survey control with Faro Targets

The Faro targets a slightly larger then the Leica in size but still experienced the same issue of obstruction of the plaques with the ssp's figure 3.58. Faro targets were used with the faro scanner and the same happened with the Leica this was only fair to the manufactures for accuracy.

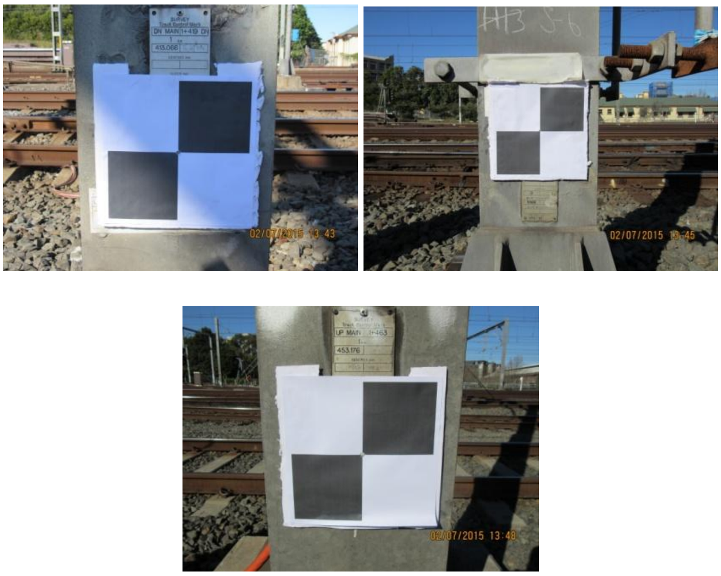


Figure 3.58 Plaque positions near the SSP's.

3.14 Conclusion

All of project phases outlined in this chapter have been completed. A detailed analysis of the data will be discussed in the next chapter together with the results. The scanning within the rail corridor was limited to only one scan position for each scanner due to time constrains and safety restrictions in that area at that particular time that could not have been foreseen.

Chapter Four - Results and Discussion

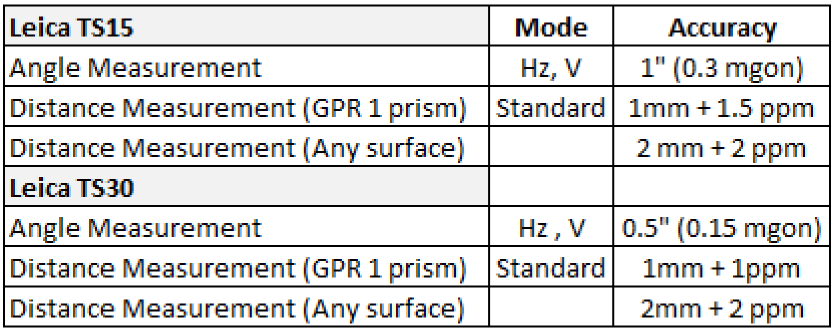
4.1 Introduction

In this chapter all the calculations have been completed, to determine the final X,Y,Z values of each target in the calibration room. The software used for the least square calculations is Comprail / Compnet 2.8 railway custom software. Least square methodology is used to calculate error components and precisions. Civilcad 7 survey software was used to calculate the least square Transformations and the joins between targets for an independent check. The final results will conform if the scanners meet Sydney Train requirements.

4.2 STS Reductions

Seventy targets were installed in the calibration room. Each target was signalised by radiating it in two faces from threes stations. The stations were established by measuring six full arcs, from each station. To maintain independent checks Two different STS's were used to establish the survey control. Both STS instruments were tested over a certified baseline prior to being used in this project, refer to Appendix I for the results of the calibrations. A summary of the manufactures specifications for the STS's are shown below in Table 4.1

Table 4.1 Leica STS specifications



Leica TS15	**Mode**	**Accuracy**
Angle Measurement	Hz, V	1" (0.3 mgon)
Distance Measurement (GPR 1 prism)	Standard	1mm + 1.5 ppm
Distance Measurement (Any surface)		2 mm + 2 ppm
Leica TS30		
Angle Measurement	Hz , V	0.5" (0.15 mgon)
Distance Measurement (GPR 1 prism)	Standard	1mm + 1ppm
Distance Measurement (Any surface)		2mm + 2 ppm

It is very important to note the specifications assume that the Target is perfectly aligned to the instrument. The Sydney Trains Specification SPC211 - Survey states the requirements for Survey control and survey of TCM's measurements is for the standard deviation of distance to be < +- 2mm + 3ppm. The standard deviation of horizontal angles is < 1.5 ".

4.2.1 Survey Control

The precision of the survey ground control established and measured in the calibration room was within 3seconds in the horizontal and 4seconds in the vertical. Refer to Appendix J for the GSI data files.

4.2.2 Targets

All of the targets installed in the calibration room were measured in two faces, from three stations, using two different Survey Total Stations. This process provided confidence in the data sets measured in terms of their accuracy, reliability and independence.

The following steps had to be completed in order to calculate the final X,Y,Z values for each target. The first stage was the reductions from the Leica TS15 and the second stage was the Leica TS30. A final comparison will be made and a table of final coordinates and heights for each Target will be shown.

4.2.3 Stage 1 Leica TS15

Step 1 - The coordinates of each target from each set up had to be compared. By using a different point ID for each target from each setup the Software was able to produce a comparison file showing the difference in X,Y,Z values for each target measured from a different station. During the field work in the calibration I decided to use Point ID's 1-70 for the measurements from Station 100. From Station 200 the point ID's were 201-270 and from Station 300 the point ID's were 301-370. This logical approach assisted during comparison. This process also ensured the software would not combine and average values with the same ID point numbers.

Step 2 - A tolerance of greater then +-2mm was set for the comparison, to maintain conformance with specification, for each target in the X,Y and Z values.

Step 3 - Targets outside the tolerance are shown in table 4.2 .

Table 4.2 Comparison of Target from TS15 data set.

	From Station			Error in (mm)		
Target ID	**100**	**200**	**300**	**X**	**Y**	**Z**
14	★		★		+ 3	
15	★		★		+ 3	
16	★	★	★		+ 3	
26	★	★			+ 3	
30	★	★			+ 3	
59	★		★		+ 3	
60	★		★		+ 3	
61	★	★	★		+ 3	
63	★	★	★		+ 3	
64	★	★			+ 3	
65	★	★				-3

The mark (★) indicates which station the target was measured from. Target 16, 61, and 63 have been automatically discarded as they have produced error from all stations.

Step 4 - If a photograph of the laser dot was available for that target, it was used as evidence to decide if a target shown in Table 4.3 would be discarded. Due to time constrains in the project not every reflectorless laser dot measurement at each target from each setup was photographed. The targets to investigate are 14, 15, 26, 30, 59, 60, 64 and 65.

From Station 100 Target 26 (a), 64 (b), and 65 have been photographed. As it can be seen from the photos in Figure 4.1 Target 64 has an error due to the blow out of the reflectorless measurement and will be discarded.

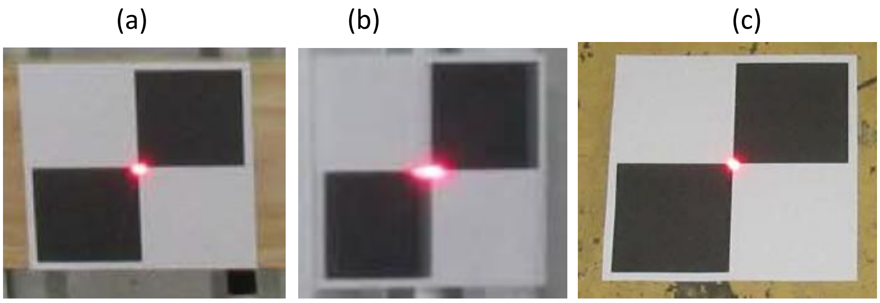


Figure 4.1 Laser dot photos from station 100

From Station 200 Target 26 and 65 have been photographed. From Figure 4.2 it can be clearly seen that the laser dot for both targets has been blown causing an error so these two targets will also be discarded.

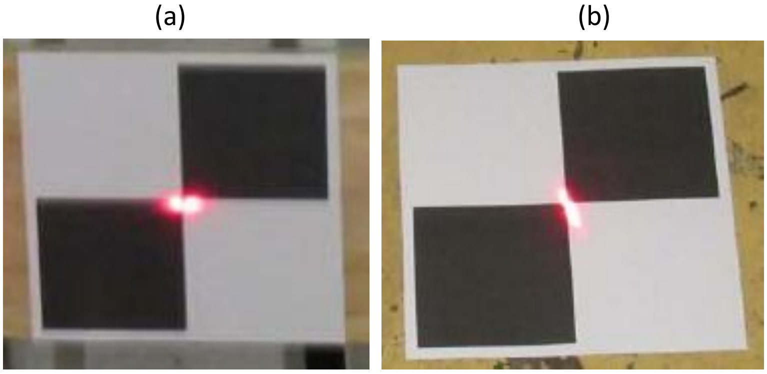
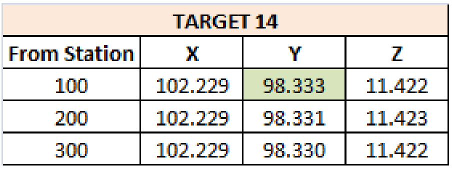

(a) (b)

Figure 4.2 Laser dot photos from station 200

From station 300 Target 14, 15, 59 and 60 were not photographed.

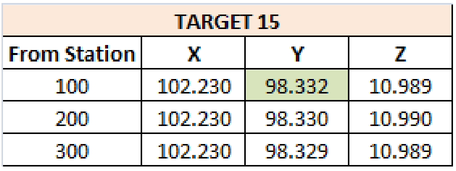
Step 5 - In this step the remaining Targets that still carry an error are 14, 15, 30, 59 and 60. Looking at the coordinates of each target from each setup it can be seen that the coordinates that are outside the +-2mm acceptable tolerance, will not be used. In Table 4.3 - 4.7 this is shown.

Table 4.3 Analysis of Target 14



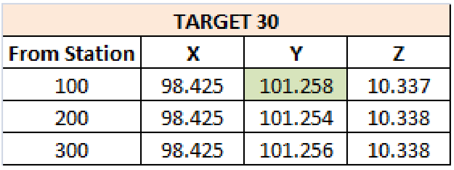
TARGET 14			
From Station	X	Y	Z
100	102.229	98.333	11.422
200	102.229	98.331	11.423
300	102.229	98.330	11.422

Table 4.4 Analysis of Target 15



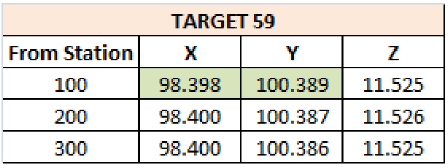
TARGET 15			
From Station	X	Y	Z
100	102.230	98.332	10.989
200	102.230	98.330	10.990
300	102.230	98.329	10.989

Table 4.5 Analysis of Target 30



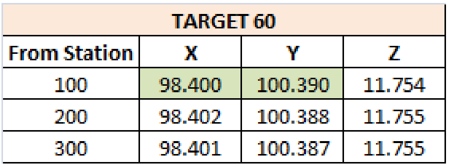
TARGET 30			
From Station	X	Y	Z
100	98.425	101.258	10.337
200	98.425	101.254	10.338
300	98.425	101.256	10.338

Table 4.6 Analysis of Target 59



TARGET 59			
From Station	X	Y	Z
100	98.398	100.389	11.525
200	98.400	100.387	11.526
300	98.400	100.386	11.525

Table 4.7 Analysis of Target 60



TARGET 60			
From Station	X	Y	Z
100	98.400	100.390	11.754
200	98.402	100.388	11.755
300	98.401	100.387	11.755

Step 6 - The remaining targets will now be averaged to determine the final coordinates. From 70 targets 10 had to be discarded, this is a good results considering 4 targets were disturbed and had fallen to the ground prior to scanning so could not be used.

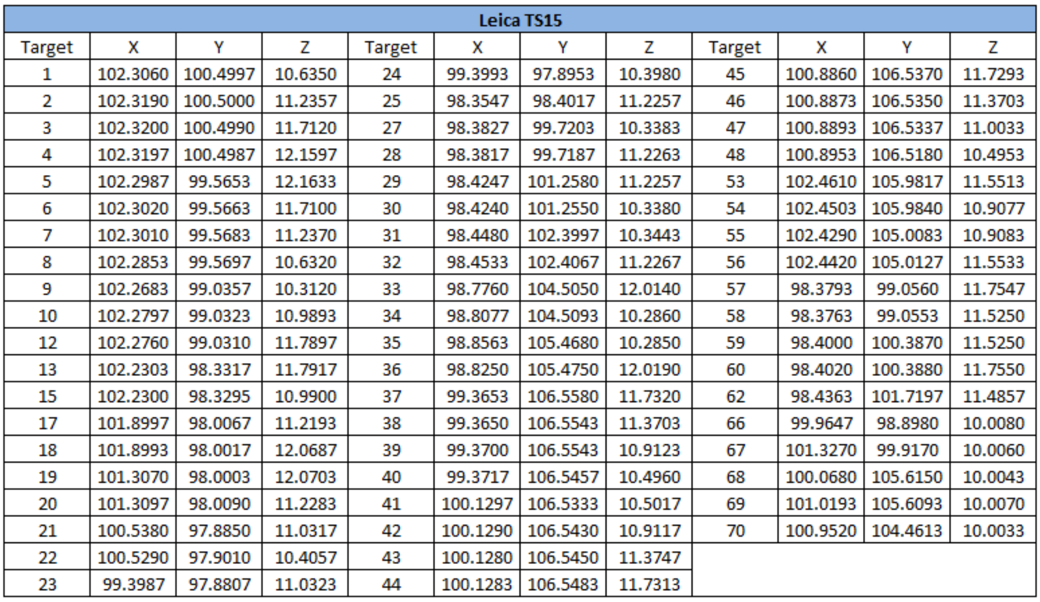
Step 7 - The horizontal and vertical distances between centre of targets, were also measured in the field. These joins were calculated and compared. Civicad 7 was used to calculate the joins. All the joins have been compared and fallen within the +-2mm tolerance except for target 11 and 14. The measurement between these targets is out of tolerance so the targets will be discarded. This results to 58 signalled final targets. This is a very good independent check on the results shown in Table 4.8. The grey areas in the table indicate one of the targets measured has been already discarded and can't be used any more. The yellow area indicates target 11 & 14 is suspect because it has fallen outside the +-2mm tolerance and will be discarded for this work.

Table 4.8 Join measurements comparison TS15 data

Targets Center (from - to)		Measured Join (m)	Calculated Join (m)	Diff (mm)	Targets Center (from - to)		Measured Join (m)	Calculated Join (m)	Diff (mm)
4	**5**	0.933	0.934	-1	**39**	**42**	0.759	0.759	0
3	**6**	0.933	0.933	0	**58**	**59**	1.331	1.332	-1
2	**7**	0.932	0.932	0	**57**	**58**	0.230	0.230	0
1	**8**	0.931	0.930	1	**60**	**59**	0.228	0.230	-2
4	**3**	0.447	0.448	-1	**61**	**63**	1.326		
3	**2**	0.476	0.476	0	**62**	**64**	1.326		
2	**1**	0.600	0.601	-1	**61**	**62**	0.256		
5	**6**	0.453	0.453	0	**63**	**64**	0.253		
6	**7**	0.474	0.473	1	**25**	**28**	1.316	1.317	-1
7	**8**	0.603	0.605	-2	**26**	**27**	1.318		
12	**13**	0.700	0.701	-1	**28**	**29**	1.539	1.540	-1
11	**14**	0.701	0.704	-3	**27**	**30**	1.536	1.536	0
10	**15**	0.703	0.704	-1	**29**	**32**	1.150	1.149	1
9	**16**	0.707			**30**	**31**	1.143	1.145	-2
12	**11**	0.368	0.368	0	**25**	**26**	0.886		
11	**10**	0.432	0.433	-1	**28**	**27**	0.887	0.888	-1
10	**9**	0.677	0.677	0	**29**	**30**	0.887	0.888	-1
13	**14**	0.367	0.369	-2	**32**	**31**	0.881	0.883	-2
14	**15**	0.432	0.433	-1	**37**	**44**	0.764	0.763	1
15	**16**	0.677			**38**	**43**	0.763	0.763	0
18	**19**	0.593	0.592	1	**40**	**41**	0.758	0.758	0
17	**20**	0.592	0.590	2	**37**	**38**	0.361	0.362	-1
18	**17**	0.848	0.850	-2	**38**	**39**	0.459	0.458	1
19	**20**	0.842	0.842	0	**39**	**40**	0.415	0.416	-1
21	**23**	1.139	1.139	0	**44**	**43**	0.357	0.356	1
22	**24**	1.129	1.130	-1	**43**	**42**	0.463	0.463	0
21	**22**	0.626	0.626	0	**42**	**41**	0.409	0.410	-1
23	**24**	0.635	0.634	1	**45**	**52**	0.759		
33	**36**	0.973	0.971	2	**46**	**51**	0.755		
34	**35**	0.960	0.960	0	**47**	**50**	0.752		
33	**34**	1.729	1.728	1	**48**	**49**	0.746		
36	**35**	1.733	1.734	-1	**45**	**46**	0.358	0.359	-1
53	**56**	0.969	0.969	0	**46**	**47**	0.367	0.367	0
54	**55**	0.976	0.976	0	**47**	**48**	0.507	0.508	-1
53	**54**	0.643	0.643	0	**52**	**51**	0.364		
56	**55**	0.645	0.645	0	**51**	**50**	0.367		
57	**60**	1.332	1.332	0	**50**	**49**	0.506		

Step 8 - The final coordinated targets measured from the TS15, have now been tabulated. Table 4.9

Table 4.9 Final Coordinates of Targets from TS15



Leica TS15											
Target	X	Y	Z	Target	X	Y	Z	Target	X	Y	Z
1	102.3060	100.4997	10.6350	24	99.3993	97.8953	10.3980	45	100.8860	106.5370	11.7293
2	102.3190	100.5000	11.2357	25	98.3547	98.4017	11.2257	46	100.8873	106.5350	11.3703
3	102.3200	100.4990	11.7120	27	98.3827	99.7203	10.3383	47	100.8893	106.5337	11.0033
4	102.3197	100.4987	12.1597	28	98.3817	99.7187	11.2263	48	100.8953	106.5180	10.4953
5	102.2987	99.5653	12.1633	29	98.4247	101.2580	11.2257	53	102.4610	105.9817	11.5513
6	102.3020	99.5663	11.7100	30	98.4240	101.2550	10.3380	54	102.4503	105.9840	10.9077
7	102.3010	99.5683	11.2370	31	98.4480	102.3997	10.3443	55	102.4290	105.0083	10.9083
8	102.2853	99.5697	10.6320	32	98.4533	102.4067	11.2267	56	102.4420	105.0127	11.5533
9	102.2683	99.0357	10.3120	33	98.7760	104.5050	12.0140	57	98.3793	99.0560	11.7547
10	102.2797	99.0323	10.9893	34	98.8077	104.5093	10.2860	58	98.3763	99.0553	11.5250
12	102.2760	99.0310	11.7897	35	98.8563	105.4680	10.2850	59	98.4000	100.3870	11.5250
13	102.2303	98.3317	11.7917	36	98.8250	105.4750	12.0190	60	98.4020	100.3880	11.7550
15	102.2300	98.3295	10.9900	37	99.3653	106.5580	11.7320	62	98.4363	101.7197	11.4857
17	101.8997	98.0067	11.2193	38	99.3650	106.5543	11.3703	66	99.9647	98.8980	10.0080
18	101.8993	98.0017	12.0687	39	99.3700	106.5543	10.9123	67	101.3270	99.9170	10.0060
19	101.3070	98.0003	12.0703	40	99.3717	106.5457	10.4960	68	100.0680	105.6150	10.0043
20	101.3097	98.0090	11.2283	41	100.1297	106.5333	10.5017	69	101.0193	105.6093	10.0070
21	100.5380	97.8850	11.0317	42	100.1290	106.5430	10.9117	70	100.9520	104.4613	10.0033
22	100.5290	97.9010	10.4057	43	100.1280	106.5450	11.3747				
23	99.3987	97.8807	11.0323	44	100.1283	106.5483	11.7313				

4.2.4 Stage 2 Leica TS30

Steps 1 to 8 will now be repeated using the data from the Leica TS30. Step 1 and 2 is exactly the same for both instruments so we can go straight into step 3.

Step 3 - Targets outside the tolerance are shown in Table 4.10

Table 4.10 Comparison of Target from TS30 data set.

	From Station			Error in (mm)		
Target ID	**100**	**200**	**300**	**X**	**Y**	**Z**
4	★		★	-13	+15	-6
11	★		★	-3		
14	★		★		+3	
15	★		★		+4	
16	★		★	-4	+6	
25	★	★			+3	
26	★	★			+5	
32	★	★			-3	

The mark (★) indicates which station the target was measured from. As the table shows no target will be automatically discarded as they have not produced errors from all three stations. That said the fact that targets 14, 15, 16 and 26 have been flagged again being outside the +-2mm tolerance so they will be automatically discarded.

Step 4 - The Targets that have been photographed are 4, 11, 25, 32. The photos will be examined to decide if any of these targets can be discarded.

From station 100 Targets 4 (a), 25 (b) and 32 (c) have been photographed and shown in figure 4.3. Examining the photos from this station the laser dot is not abnormal.

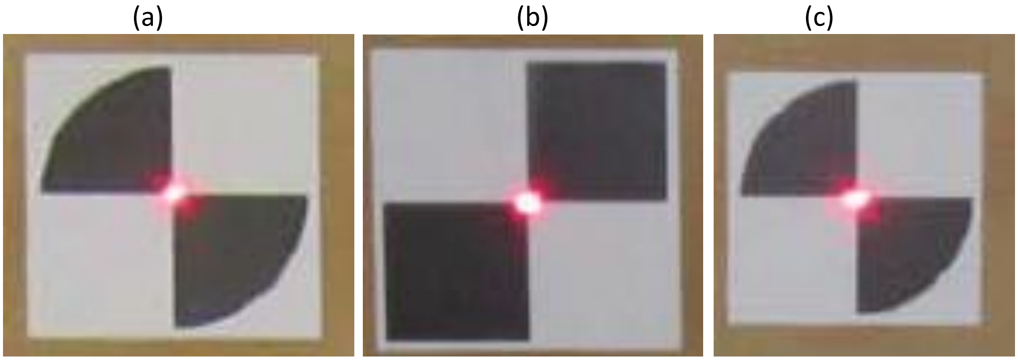


Figure 4.3 Laser dot photos from station 100

From station 200 targets 25 (a) and 32 (b) have been photographed Figure 4.4 and it can be clearly seen that the laser dot has blown out and these two targets will be discarded.

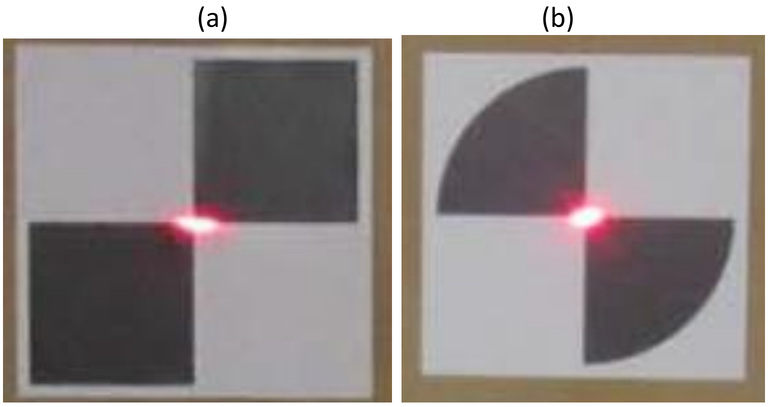


Figure 4.4 Laser dot photos from station 200

From station 300 target 4 (a) was photographed as shown in figure 4.5.As it can be seen from the photo the laser dot has blown out and this target will be discarded.

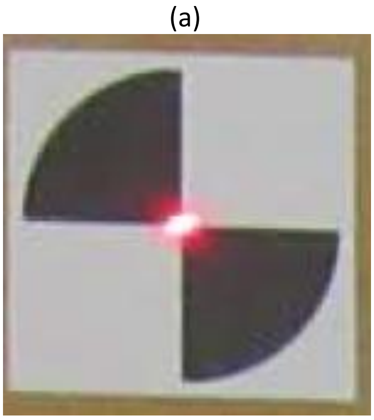


Figure 4.5 Laser dot from station 300

It is interesting to note the least square adjustment from the rail software confirmed target 4 has a 3D residual of -0.015mm.

Step 5 - In this step the remaining Target 11 is still carrying an error. Looking at the coordinates of the target from each setup it can be seen that the coordinates that are outside the +-2mm acceptable tolerance, will not be used Table 4.11.

Table 4.11 Analysis of Target 11

TARGET 11			
From Station	X	Y	Z
100	102.273	99.034	11.421
200	102.275	99.035	11.423
300	102.276	99.034	11.421

Step 6 - The remaining targets will now be averaged to determine the final coordinates for each target. From 70 targets 7 had to be discarded again a great results.

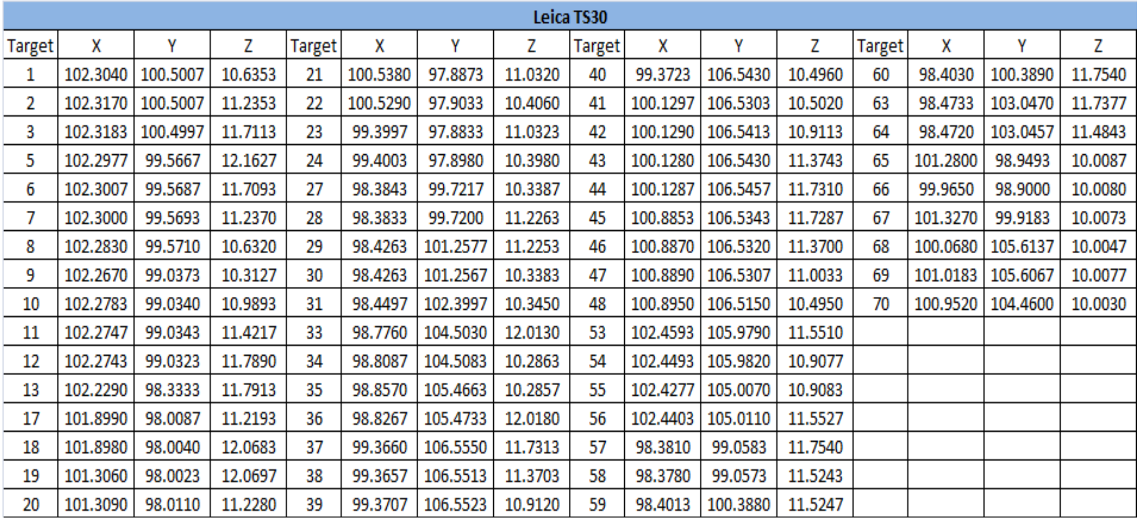
Step 7 - The joins will now be calculated and compared and shoen in Table 4.12. The grey areas in the table indicate one of the targets measured has been already discarded and can't be used any more. The yellow area indicates target 61 & 62 is suspect because it has fallen outside the 2mm tolerance and will be discarded for this work

Table 4.12 Join measurements comparison TS30 data

Targets Center (from - to)		Measured Join (m)	Calculated Join (m)	Diff (mm)	Targets Center (from - to)		Measured Join (m)	Calculated Join (m)	Diff (mm)
4	5	0.933			58	59	1.331	1.331	0
3	6	0.933	0.931	2	57	58	0.230	0.230	0
2	7	0.932	0.932	0	60	59	0.228	0.229	-1
1	8	0.931	0.930	1	61	63	1.326	1.325	1
4	3	0.447			62	64	1.326	1.326	0
3	2	0.476	0.476	0	61	62	0.256	0.253	3
2	1	0.600	0.600	0	63	64	0.253	0.254	-1
5	6	0.453	0.454	-1	25	28	1.316		
6	7	0.474	0.472	2	26	27	1.318		
7	8	0.603	0.605	-2	28	29	1.539	1.539	0
12	13	0.700	0.700	0	27	30	1.536	1.536	0
11	14	0.701			29	32	1.150		
10	15	0.703			30	31	1.143	1.143	0
9	16	0.707			25	26	0.886		
12	11	0.368	0.367	1	28	27	0.887	0.887	0
11	10	0.432	0.433	-1	29	30	0.887	0.887	0
10	9	0.677	0.676	1	32	31	0.881		
13	14	0.367			37	44	0.764	0.763	1
14	15	0.432			38	43	0.763	0.762	1
15	16	0.677			39	42	0.759	0.758	1
18	19	0.593	0.592	1	40	41	0.758	0.758	0
17	20	0.592	0.590	2	37	38	0.361	0.361	0
18	17	0.848	0.849	-1	38	39	0.459	0.458	1
19	20	0.842	0.842	0	39	40	0.415	0.416	-1
21	23	1.139	1.138	1	44	43	0.357	0.357	0
22	24	1.129	1.129	0	43	42	0.463	0.463	0
21	22	0.626	0.626	0	42	41	0.409	0.409	0
23	24	0.635	0.634	1	45	52	0.759		
33	36	0.973	0.971	2	46	51	0.755		
34	35	0.960	0.959	1	47	50	0.752		
33	34	1.729	1.727	2	48	49	0.746		
36	35	1.733	1.732	1	45	46	0.358	0.359	-1
53	56	0.969	0.968	1	46	47	0.367	0.367	0
54	55	0.976	0.975	1	47	48	0.507	0.508	-1
53	54	0.643	0.643	0	52	51	0.364		
56	55	0.645	0.645	0	51	50	0.367		
57	60	1.332	1.331	1	50	49	0.506		

Step 8 - The final signalised coordinated targets measured from the TS30, have now been tabulated refer to table 4.13.

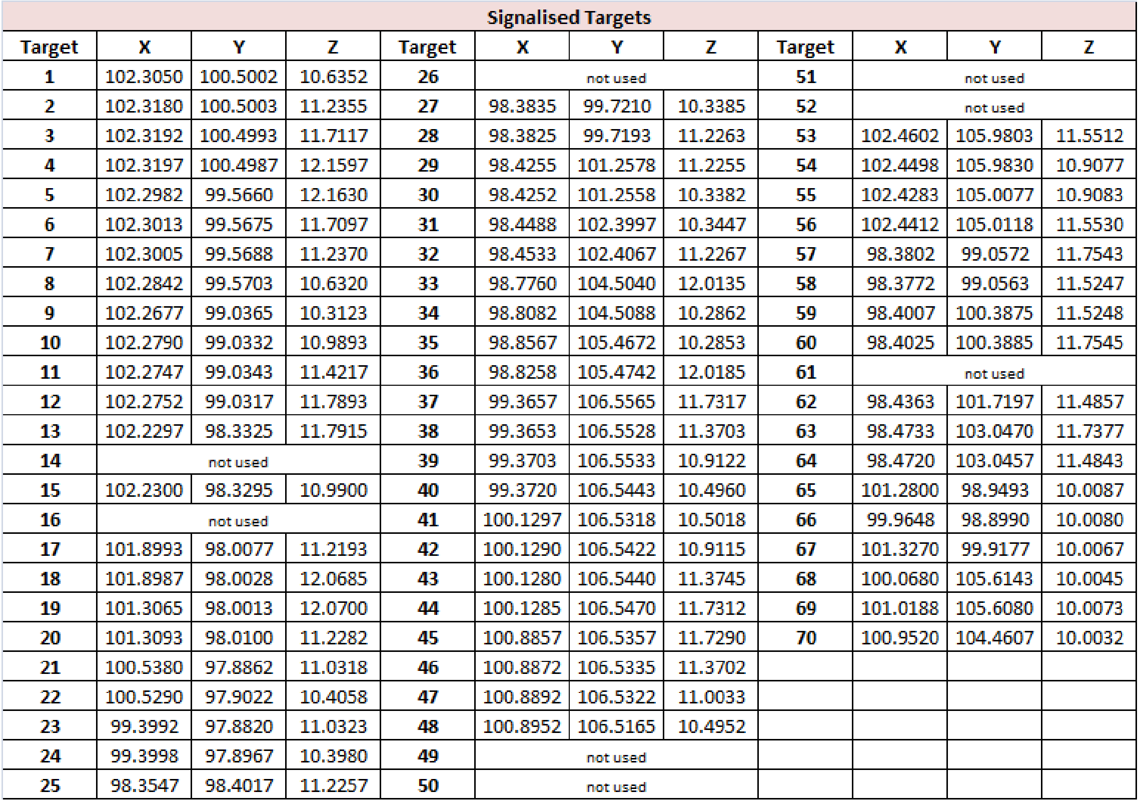
Table 4.13 Final Coordinates of signalized Targets from TS30



Leica TS30															
Target	X	Y	Z	Target	X	Y	Z	Target	X	Y	Z	Target	X	Y	Z
1	102.3040	100.5007	10.6353	21	100.5380	97.8873	11.0320	40	99.3723	106.5430	10.4960	60	98.4030	100.3890	11.7540
2	102.3170	100.5007	11.2353	22	100.5290	97.9033	10.4060	41	100.1297	106.5303	10.5020	63	98.4733	103.0470	11.7377
3	102.3183	100.4997	11.7113	23	99.3997	97.8833	11.0323	42	100.1290	106.5413	10.9113	64	98.4720	103.0457	11.4843
5	102.2977	99.5667	12.1627	24	99.4003	97.8980	10.3980	43	100.1280	106.5430	11.3743	65	101.2800	98.9493	10.0087
6	102.3007	99.5687	11.7093	27	98.3843	99.7217	10.3387	44	100.1287	106.5457	11.7310	66	99.9650	98.9000	10.0080
7	102.3000	99.5693	11.2370	28	98.3833	99.7200	11.2263	45	100.8853	106.5343	11.7287	67	101.3270	99.9183	10.0073
8	102.2830	99.5710	10.6320	29	98.4263	101.2577	11.2253	46	100.8870	106.5320	11.3700	68	100.0680	105.6137	10.0047
9	102.2670	99.0373	10.3127	30	98.4263	101.2567	10.3383	47	100.8890	106.5307	11.0033	69	101.0183	105.6067	10.0077
10	102.2783	99.0340	10.9893	31	98.4497	102.3997	10.3450	48	100.8950	106.5150	10.4950	70	100.9520	104.4600	10.0030
11	102.2747	99.0343	11.4217	33	98.7760	104.5030	12.0130	53	102.4593	105.9790	11.5510				
12	102.2743	99.0323	11.7890	34	98.8087	104.5083	10.2863	54	102.4493	105.9820	10.9077				
13	102.2290	98.3333	11.7913	35	98.8570	105.4663	10.2857	55	102.4277	105.0070	10.9083				
17	101.8990	98.0087	11.2193	36	98.8267	105.4733	12.0180	56	102.4403	105.0110	11.5527				
18	101.8980	98.0040	12.0683	37	99.3660	106.5550	11.7313	57	98.3810	99.0583	11.7540				
19	101.3060	98.0023	12.0697	38	99.3657	106.5513	11.3703	58	98.3780	99.0573	11.5243				
20	101.3090	98.0110	11.2280	39	99.3707	106.5523	10.9120	59	98.4013	100.3880	11.5247				

Now that the final error free coordinates have been finalized from the two STS's a comparison was done and a final data set of coordinated signalized targets has been produced in Table 4.14. Targets showing two values within tolerance were averaged. During the comparison Targets 23, 24, 37, 38, 40, 41, 44-48, 53 and 69 were outside the +-2mm tolerance.

Table 4.14 Final Combined Coordinates of signalized Targets from TS15 & 30



Signalised Targets											
Target	**X**	**Y**	**Z**	**Target**	**X**	**Y**	**Z**	**Target**	**X**	**Y**	**Z**
1	102.3050	100.5002	10.6352	**26**	not used			**51**	not used		
2	102.3180	100.5003	11.2355	**27**	98.3835	99.7210	10.3385	**52**	not used		
3	102.3192	100.4993	11.7117	**28**	98.3825	99.7193	11.2263	**53**	102.4602	105.9803	11.5512
4	102.3197	100.4987	12.1597	**29**	98.4255	101.2578	11.2255	**54**	102.4498	105.9830	10.9077
5	102.2982	99.5660	12.1630	**30**	98.4252	101.2558	10.3382	**55**	102.4283	105.0077	10.9083
6	102.3013	99.5675	11.7097	**31**	98.4488	102.3997	10.3447	**56**	102.4412	105.0118	11.5530
7	102.3005	99.5688	11.2370	**32**	98.4533	102.4067	11.2267	**57**	98.3802	99.0572	11.7543
8	102.2842	99.5703	10.6320	**33**	98.7760	104.5040	12.0135	**58**	98.3772	99.0563	11.5247
9	102.2677	99.0365	10.3123	**34**	98.8082	104.5088	10.2862	**59**	98.4007	100.3875	11.5248
10	102.2790	99.0332	10.9893	**35**	98.8567	105.4672	10.2853	**60**	98.4025	100.3885	11.7545
11	102.2747	99.0343	11.4217	**36**	98.8258	105.4742	12.0185	**61**	not used		
12	102.2752	99.0317	11.7893	**37**	99.3657	106.5565	11.7317	**62**	98.4363	101.7197	11.4857
13	102.2297	98.3325	11.7915	**38**	99.3653	106.5528	11.3703	**63**	98.4733	103.0470	11.7377
14	not used			**39**	99.3703	106.5533	10.9122	**64**	98.4720	103.0457	11.4843
15	102.2300	98.3295	10.9900	**40**	99.3720	106.5443	10.4960	**65**	101.2800	98.9493	10.0087
16	not used			**41**	100.1297	106.5318	10.5018	**66**	99.9648	98.8990	10.0080
17	101.8993	98.0077	11.2193	**42**	100.1290	106.5422	10.9115	**67**	101.3270	99.9177	10.0067
18	101.8987	98.0028	12.0685	**43**	100.1280	106.5440	11.3745	**68**	100.0680	105.6143	10.0045
19	101.3065	98.0013	12.0700	**44**	100.1285	106.5470	11.7312	**69**	101.0188	105.6080	10.0073
20	101.3093	98.0100	11.2282	**45**	100.8857	106.5357	11.7290	**70**	100.9520	104.4607	10.0032
21	100.5380	97.8862	11.0318	**46**	100.8872	106.5335	11.3702				
22	100.5290	97.9022	10.4058	**47**	100.8892	106.5322	11.0033				
23	99.3992	97.8820	11.0323	**48**	100.8952	106.5165	10.4952				
24	99.3998	97.8967	10.3980	**49**	not used						
25	98.3547	98.4017	11.2257	**50**	not used						

4.3 Scanner Reductions

The reduction of the scanner data were completed in two stages. The two scanners used in this research project was the Faro Focus 3D X330 and the Leica P20.

This scanner project work is point based. This means using targets whose centroids can be extracted using the scanner software. The scanner was setup in three different positions in the calibration room and at different heights. The scanners were not setup over a known mark meaning indirect georefrencing was done. The literature review showed to self calibrate a scanner, various methods had been determined in the past. None provide a process that was similar to a Survey Total Station for a Surveyor to pick up on and determine systematic errors of a TLS. In the literature review MATLAB software were used for the calibration by designing an appropriate model. Due to time constraints and loss of time due to the relocation of the indoor calibration room, MATLAB was not used in this work. The 3D positional coordinate accuracy will be determined for each scanner and then compared to the 3D coordinates of the signalised targets.

It was very important that the calibration targets are signalized independently by a STS. This allows for the comparison of STS data and TLS data to determine accuracy. If the accuracy from both instruments is within the acceptable range of +-2mm then we can use the TLS in the rail corridor.

The scanner data sets had to converted from scanners space to ground based coordinates. the Six parameter Helmert transformation could be used. Within the scanner software Cyclone and Scene a transformation is called a registration, this function could also be used. In this research Civilcad7 will be used for the transformation of the scanner data sets to the indoor calibration room local ground coordinate system. It is important to note the scanner software from both manufactures is not that easy to learn within a very small time frame, this is why Civilcad was chosen for the transformations. When all the three scanner data sets have been transformed a coordinate comparison will be done.

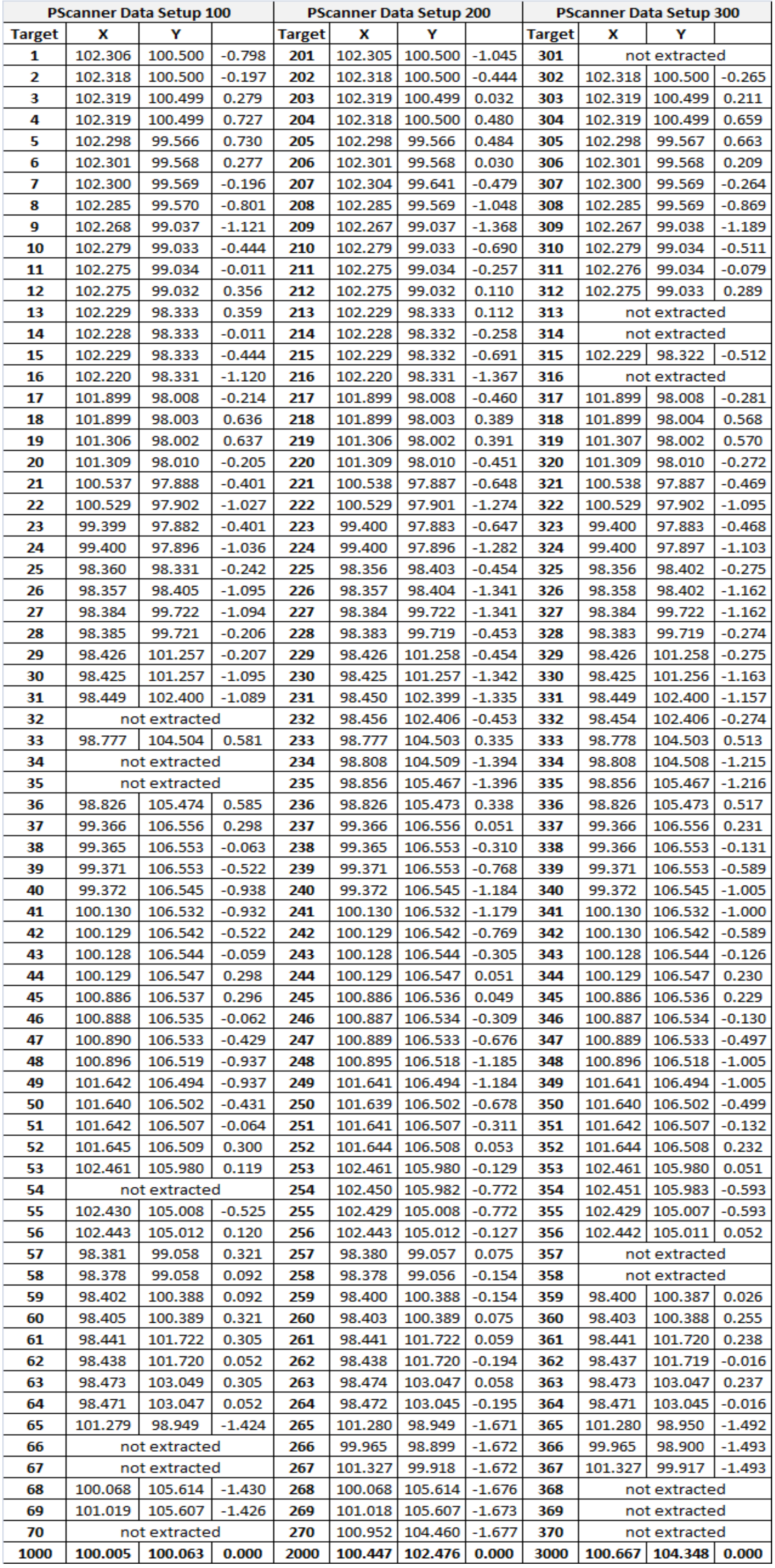
4.3.1 Stage 1 Leica P20

Step 1 - Transformation of the three scanner data sets using three points. Target 20, 29, and 43 were used for the transformation. The incident angles, height above ground and general placement position within the calibration space of these three targets aided in their selection as transformation base points.

The raw target centroids were exported from the Leica Cyclone 9.0 software as a SVY file which is a simple tab delimited text file. This data was put in order of Point Number, easting, Northing and Elevation and imported into CivilCad 7.0 individually and not as a bundle, for transformation. This was done for all three scanner data sets. During the transformation the residuals were zero. Once transformed the scanner data was exported as a txt file and imported into an excel spreadsheet for comparison.

Step 2 - Table 4.15 shows the XYZ values for each target .

Table 4.15 Leica P20 Transformed scanner target centroids



PScanner Data Setup 100				PScanner Data Setup 200				PScanner Data Setup 300			
Target	**X**	**Y**		**Target**	**X**	**Y**		**Target**	**X**	**Y**	
1	102.306	100.500	-0.798	**201**	102.305	100.500	-1.045	**301**	not extracted		
2	102.318	100.500	-0.197	**202**	102.318	100.500	-0.444	**302**	102.318	100.500	-0.265
3	102.319	100.499	0.279	**203**	102.319	100.499	0.032	**303**	102.319	100.499	0.211
4	102.319	100.499	0.727	**204**	102.318	100.500	0.480	**304**	102.319	100.499	0.659
5	102.298	99.566	0.730	**205**	102.298	99.566	0.484	**305**	102.298	99.567	0.663
6	102.301	99.568	0.277	**206**	102.301	99.568	0.030	**306**	102.301	99.568	0.209
7	102.300	99.569	-0.196	**207**	102.304	99.641	-0.479	**307**	102.300	99.569	-0.264
8	102.285	99.570	-0.801	**208**	102.285	99.569	-1.048	**308**	102.285	99.569	-0.869
9	102.268	99.037	-1.121	**209**	102.267	99.037	-1.368	**309**	102.267	99.038	-1.189
10	102.279	99.033	-0.444	**210**	102.279	99.033	-0.690	**310**	102.279	99.034	-0.511
11	102.275	99.034	-0.011	**211**	102.275	99.034	-0.257	**311**	102.276	99.034	-0.079
12	102.275	99.032	0.356	**212**	102.275	99.032	0.110	**312**	102.275	99.033	0.289
13	102.229	98.333	0.359	**213**	102.229	98.333	0.112	**313**	not extracted		
14	102.228	98.333	-0.011	**214**	102.228	98.332	-0.258	**314**	not extracted		
15	102.229	98.333	-0.444	**215**	102.229	98.332	-0.691	**315**	102.229	98.322	-0.512
16	102.220	98.331	-1.120	**216**	102.220	98.331	-1.367	**316**	not extracted		
17	101.899	98.008	-0.214	**217**	101.899	98.008	-0.460	**317**	101.899	98.008	-0.281
18	101.899	98.003	0.636	**218**	101.899	98.003	0.389	**318**	101.899	98.004	0.568
19	101.306	98.002	0.637	**219**	101.306	98.002	0.391	**319**	101.307	98.002	0.570
20	101.309	98.010	-0.205	**220**	101.309	98.010	-0.451	**320**	101.309	98.010	-0.272
21	100.537	97.888	-0.401	**221**	100.538	97.887	-0.648	**321**	100.538	97.887	-0.469
22	100.529	97.902	-1.027	**222**	100.529	97.901	-1.274	**322**	100.529	97.902	-1.095
23	99.399	97.882	-0.401	**223**	99.400	97.883	-0.647	**323**	99.400	97.883	-0.468
24	99.400	97.896	-1.036	**224**	99.400	97.896	-1.282	**324**	99.400	97.897	-1.103
25	98.360	98.331	-0.242	**225**	98.356	98.403	-0.454	**325**	98.356	98.402	-0.275
26	98.357	98.405	-1.095	**226**	98.357	98.404	-1.341	**326**	98.358	98.402	-1.162
27	98.384	99.722	-1.094	**227**	98.384	99.722	-1.341	**327**	98.384	99.722	-1.162
28	98.385	99.721	-0.206	**228**	98.383	99.719	-0.453	**328**	98.383	99.719	-0.274
29	98.426	101.257	-0.207	**229**	98.426	101.258	-0.454	**329**	98.426	101.258	-0.275
30	98.425	101.257	-1.095	**230**	98.425	101.257	-1.342	**330**	98.425	101.256	-1.163
31	98.449	102.400	-1.089	**231**	98.450	102.399	-1.335	**331**	98.449	102.400	-1.157
32	not extracted			**232**	98.456	102.406	-0.453	**332**	98.454	102.406	-0.274
33	98.777	104.504	0.581	**233**	98.777	104.503	0.335	**333**	98.778	104.503	0.513
34	not extracted			**234**	98.808	104.509	-1.394	**334**	98.808	104.508	-1.215
35	not extracted			**235**	98.856	105.467	-1.396	**335**	98.856	105.467	-1.216
36	98.826	105.474	0.585	**236**	98.826	105.473	0.338	**336**	98.826	105.473	0.517
37	99.366	106.556	0.298	**237**	99.366	106.556	0.051	**337**	99.366	106.556	0.231
38	99.365	106.553	-0.063	**238**	99.365	106.553	-0.310	**338**	99.366	106.553	-0.131
39	99.371	106.553	-0.522	**239**	99.371	106.553	-0.768	**339**	99.371	106.553	-0.589
40	99.372	106.545	-0.938	**240**	99.372	106.545	-1.184	**340**	99.372	106.545	-1.005
41	100.130	106.532	-0.932	**241**	100.130	106.532	-1.179	**341**	100.130	106.532	-1.000
42	100.129	106.542	-0.522	**242**	100.129	106.542	-0.769	**342**	100.130	106.542	-0.589
43	100.128	106.544	-0.059	**243**	100.128	106.544	-0.305	**343**	100.128	106.544	-0.126
44	100.129	106.547	0.298	**244**	100.129	106.547	0.051	**344**	100.129	106.547	0.230
45	100.886	106.537	0.296	**245**	100.886	106.536	0.049	**345**	100.886	106.536	0.229
46	100.888	106.535	-0.062	**246**	100.887	106.534	-0.309	**346**	100.887	106.534	-0.130
47	100.890	106.533	-0.429	**247**	100.889	106.533	-0.676	**347**	100.889	106.533	-0.497
48	100.896	106.519	-0.937	**248**	100.895	106.518	-1.185	**348**	100.896	106.518	-1.005
49	101.642	106.494	-0.937	**249**	101.641	106.494	-1.184	**349**	101.641	106.494	-1.005
50	101.640	106.502	-0.431	**250**	101.639	106.502	-0.678	**350**	101.640	106.502	-0.499
51	101.642	106.507	-0.064	**251**	101.641	106.507	-0.311	**351**	101.642	106.507	-0.132
52	101.645	106.509	0.300	**252**	101.644	106.508	0.053	**352**	101.644	106.508	0.232
53	102.461	105.980	0.119	**253**	102.461	105.980	-0.129	**353**	102.461	105.980	0.051
54	not extracted			**254**	102.450	105.982	-0.772	**354**	102.451	105.983	-0.593
55	102.430	105.008	-0.525	**255**	102.429	105.008	-0.772	**355**	102.429	105.007	-0.593
56	102.443	105.012	0.120	**256**	102.443	105.012	-0.127	**356**	102.442	105.011	0.052
57	98.381	99.058	0.321	**257**	98.380	99.057	0.075	**357**	not extracted		
58	98.378	99.058	0.092	**258**	98.378	99.056	-0.154	**358**	not extracted		
59	98.402	100.388	0.092	**259**	98.400	100.388	-0.154	**359**	98.400	100.387	0.026
60	98.405	100.389	0.321	**260**	98.403	100.389	0.075	**360**	98.403	100.388	0.255
61	98.441	101.722	0.305	**261**	98.441	101.722	0.059	**361**	98.441	101.720	0.238
62	98.438	101.720	0.052	**262**	98.438	101.720	-0.194	**362**	98.437	101.719	-0.016
63	98.473	103.049	0.305	**263**	98.474	103.047	0.058	**363**	98.473	103.047	0.237
64	98.471	103.047	0.052	**264**	98.472	103.045	-0.195	**364**	98.471	103.045	-0.016
65	101.279	98.949	-1.424	**265**	101.280	98.949	-1.671	**365**	101.280	98.950	-1.492
66	not extracted			**266**	99.965	98.899	-1.672	**366**	99.965	98.900	-1.493
67	not extracted			**267**	101.327	99.918	-1.672	**367**	101.327	99.917	-1.493
68	100.068	105.614	-1.430	**268**	100.068	105.614	-1.676	**368**	not extracted		
69	101.019	105.607	-1.426	**269**	101.018	105.607	-1.673	**369**	not extracted		
70	not extracted			**270**	100.952	104.460	-1.677	**370**	not extracted		
1000	**100.005**	**100.063**	**0.000**	**2000**	**100.447**	**102.476**	**0.000**	**3000**	**100.667**	**104.348**	**0.000**

Targets that were scanned but not extracted in the point cloud, are noted in the table. Figure 4.6 shows an example of why a target could not be extracted, in this case the shadow line of person standing near the target 70 at setup 100 (a) and target 13 extreme incident angle from setup 300 (b).

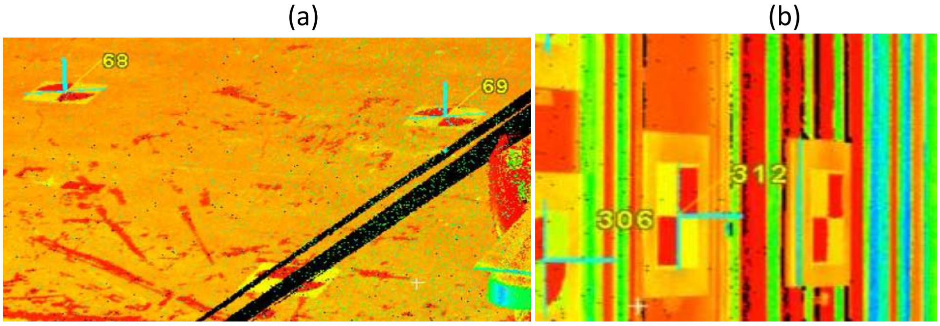


Figure 4.6 Targets not extracted

Step 3 - The Z values have not been transformed to ground values. This will be done by calculating the difference between the true target elevation and the scanner target elevation. This should be the same value for all the targets from that setup. If there is a variation in the difference of +- 2mm then the average will be calculated and adopted.

For setup 100,the value of 11.433 need to be added to all the Z values to have ground elevations.

Signalised Target RL - Scanner Target RL = Difference in RL (Constant)

$$10.635-(-0.798)=11.433$$

For setup 200,the value of 11.680 need to be added to all the Z values to have ground elevations.

Signalised Target RL - Scanner Target RL = Difference in RL (Constant)

$$10.635-(-1.045)=11.680$$

For setup 300 it is 11.501.

Signalised Target RL - Scanner Target RL = Difference in RL (Constant)

$$11.236-(-0.265)=11.501$$

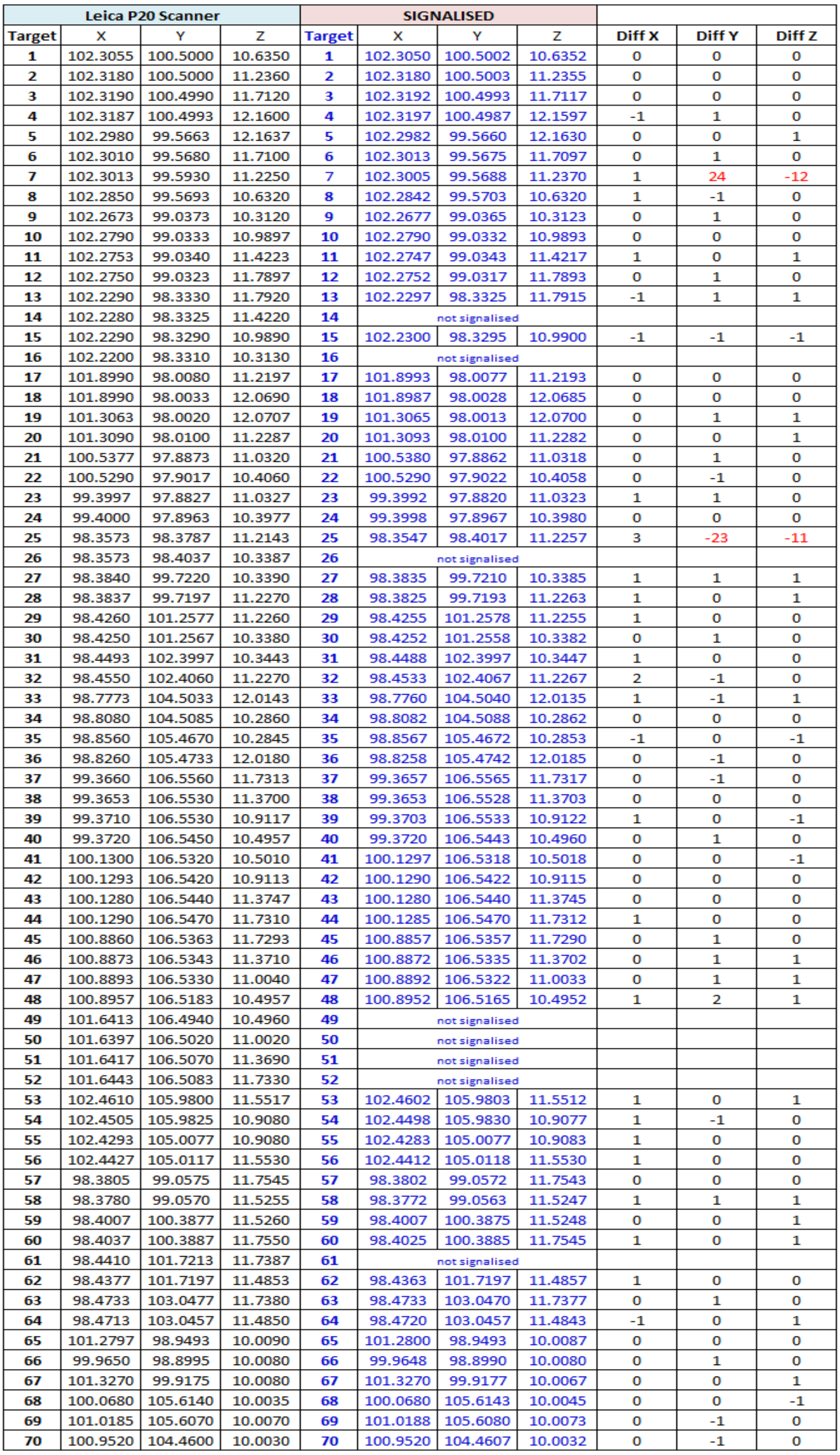
Table 4.16 shows the final scanner target centroids with the adjusted heights as well. Also note at the bottom of this table the true coordinates of the scanner.

Table 4.16 P20 Final Scanner target centroids coordinated to the indoor calibration System

Scanner Data Setup 100					Scanner Data Setup 200					Scanner Data Setup 300				
Target	**X**	**Y**		Z	**Target**	**X**	**Y**		Z	**Target**	**X**	**Y**		Z
1	102.306	100.500	-0.798	10.635	201	102.305	100.500	-1.045	10.635	301	not extracted			
2	102.318	100.500	-0.197	11.236	202	102.318	100.500	-0.444	11.236	302	102.318	100.500	-0.265	11.236
3	102.319	100.499	0.279	11.712	203	102.319	100.499	0.032	11.712	303	102.319	100.499	0.211	11.712
4	102.319	100.499	0.727	12.160	204	102.318	100.500	0.480	12.160	304	102.319	100.499	0.659	12.160
5	102.298	99.566	0.730	12.163	205	102.298	99.566	0.484	12.164	305	102.298	99.567	0.663	12.164
6	102.301	99.568	0.277	11.710	206	102.301	99.568	0.030	11.710	306	102.301	99.568	0.209	11.710
7	102.300	99.569	-0.196	11.237	207	102.304	99.641	-0.479	11.201	307	102.300	99.569	-0.264	11.237
8	102.285	99.570	-0.801	10.632	208	102.285	99.569	-1.048	10.632	308	102.285	99.569	-0.869	10.632
9	102.268	99.037	-1.121	10.312	209	102.267	99.037	-1.368	10.312	309	102.267	99.038	-1.189	10.312
10	102.279	99.033	-0.444	10.989	210	102.279	99.033	-0.690	10.990	310	102.279	99.034	-0.511	10.990
11	102.275	99.034	-0.011	11.422	211	102.275	99.034	-0.257	11.423	311	102.276	99.034	-0.079	11.422
12	102.275	99.032	0.356	11.789	212	102.275	99.032	0.110	11.790	312	102.275	99.033	0.289	11.790
13	102.229	98.333	0.359	11.792	213	102.229	98.333	0.112	11.792	313	not extracted			
14	102.228	98.333	-0.011	11.422	214	102.228	98.332	-0.258	11.422	314	not extracted			
15	102.229	98.333	-0.444	10.989	215	102.229	98.332	-0.691	10.989	315	102.229	98.322	-0.512	10.989
16	102.220	98.331	-1.120	10.313	216	102.220	98.331	-1.367	10.313	316	not extracted			
17	101.899	98.008	-0.214	11.219	217	101.899	98.008	-0.460	11.220	317	101.899	98.008	-0.281	11.220
18	101.899	98.003	0.636	12.069	218	101.899	98.003	0.389	12.069	318	101.899	98.004	0.568	12.069
19	101.306	98.002	0.637	12.070	219	101.306	98.002	0.391	12.071	319	101.307	98.002	0.570	12.071
20	101.309	98.010	-0.205	11.228	220	101.309	98.010	-0.451	11.229	320	101.309	98.010	-0.272	11.229
21	100.537	97.888	-0.401	11.032	221	100.538	97.887	-0.648	11.032	321	100.538	97.887	-0.469	11.032
22	100.529	97.902	-1.027	10.406	222	100.529	97.901	-1.274	10.406	322	100.529	97.902	-1.095	10.406
23	99.399	97.882	-0.401	11.032	223	99.400	97.883	-0.647	11.033	323	99.400	97.883	-0.468	11.033
24	99.400	97.896	-1.036	10.397	224	99.400	97.896	-1.282	10.398	324	99.400	97.897	-1.103	10.398
25	98.360	98.331	-0.242	11.191	225	98.356	98.403	-0.454	11.226	325	98.356	98.402	-0.275	11.226
26	98.357	98.405	-1.095	10.338	226	98.357	98.404	-1.341	10.339	326	98.358	98.402	-1.162	10.339
27	98.384	99.722	-1.094	10.339	227	98.384	99.722	-1.341	10.339	327	98.384	99.722	-1.162	10.339
28	98.385	99.721	-0.206	11.227	228	98.383	99.719	-0.453	11.227	328	98.383	99.719	-0.274	11.227
29	98.426	101.257	-0.207	11.226	229	98.426	101.258	-0.454	11.226	329	98.426	101.258	-0.275	11.226
30	98.425	101.257	-1.095	10.338	230	98.425	101.257	-1.342	10.338	330	98.425	101.256	-1.163	10.338
31	98.449	102.400	-1.089	10.344	231	98.450	102.399	-1.335	10.345	331	98.449	102.400	-1.157	10.344
32	not extracted				232	98.456	102.406	-0.453	11.227	332	98.454	102.406	-0.274	11.227
33	98.777	104.504	0.581	12.014	233	98.777	104.503	0.335	12.015	333	98.778	104.503	0.513	12.014
34	not extracted				234	98.808	104.509	-1.394	10.286	334	98.808	104.508	-1.215	10.286
35	not extracted				235	98.856	105.467	-1.396	10.284	335	98.856	105.467	-1.216	10.285
36	98.826	105.474	0.585	12.018	236	98.826	105.473	0.338	12.018	336	98.826	105.473	0.517	12.018
37	99.366	106.556	0.298	11.731	237	99.366	106.556	0.051	11.731	337	99.366	106.556	0.231	11.732
38	99.365	106.553	-0.063	11.370	238	99.365	106.553	-0.310	11.370	338	99.366	106.553	-0.131	11.370
39	99.371	106.553	-0.522	10.911	239	99.371	106.553	-0.768	10.912	339	99.371	106.553	-0.589	10.912
40	99.372	106.545	-0.938	10.495	240	99.372	106.545	-1.184	10.496	340	99.372	106.545	-1.005	10.496
41	100.130	106.532	-0.932	10.501	241	100.130	106.532	-1.179	10.501	341	100.130	106.532	-1.000	10.501
42	100.129	106.542	-0.522	10.911	242	100.129	106.542	-0.769	10.911	342	100.130	106.542	-0.589	10.912
43	100.128	106.544	-0.059	11.374	243	100.128	106.544	-0.305	11.375	343	100.128	106.544	-0.126	11.375
44	100.129	106.547	0.298	11.731	244	100.129	106.547	0.051	11.731	344	100.129	106.547	0.230	11.731
45	100.886	106.537	0.296	11.729	245	100.886	106.536	0.049	11.729	345	100.886	106.536	0.229	11.730
46	100.888	106.535	-0.062	11.371	246	100.887	106.534	-0.309	11.371	346	100.887	106.534	-0.130	11.371
47	100.890	106.533	-0.429	11.004	247	100.889	106.533	-0.676	11.004	347	100.889	106.533	-0.497	11.004
48	100.896	106.519	-0.937	10.496	248	100.895	106.518	-1.185	10.495	348	100.896	106.518	-1.005	10.496
49	101.642	106.494	-0.937	10.496	249	101.641	106.494	-1.184	10.496	349	101.641	106.494	-1.005	10.496
50	101.640	106.502	-0.431	11.002	250	101.639	106.502	-0.678	11.002	350	101.640	106.502	-0.499	11.002
51	101.642	106.507	-0.064	11.369	251	101.641	106.507	-0.311	11.369	351	101.642	106.507	-0.132	11.369
52	101.645	106.509	0.300	11.733	252	101.644	106.508	0.053	11.733	352	101.644	106.508	0.232	11.733
53	102.461	105.980	0.119	11.552	253	102.461	105.980	-0.129	11.551	353	102.461	105.980	0.051	11.552
54	not extracted				254	102.450	105.982	-0.772	10.908	354	102.451	105.983	-0.593	10.908
55	102.430	105.008	-0.525	10.908	255	102.429	105.008	-0.772	10.908	355	102.429	105.007	-0.593	10.908
56	102.443	105.012	0.120	11.553	256	102.443	105.012	-0.127	11.553	356	102.442	105.011	0.052	11.553
57	98.381	99.058	0.321	11.754	257	98.380	99.057	0.075	11.755	357	not extracted			
58	98.378	99.058	0.092	11.525	258	98.378	99.056	-0.154	11.526	358	not extracted			
59	98.402	100.388	0.092	11.525	259	98.400	100.388	-0.154	11.526	359	98.400	100.387	0.026	11.527
60	98.405	100.389	0.321	11.754	260	98.403	100.389	0.075	11.755	360	98.403	100.388	0.255	11.756
61	98.441	101.722	0.305	11.738	261	98.441	101.722	0.059	11.739	361	98.441	101.720	0.238	11.739
62	98.438	101.720	0.052	11.485	262	98.438	101.720	-0.194	11.486	362	98.437	101.719	-0.016	11.485
63	98.473	103.049	0.305	11.738	263	98.474	103.047	0.058	11.738	363	98.473	103.047	0.237	11.738
64	98.471	103.047	0.052	11.485	264	98.472	103.045	-0.195	11.485	364	98.471	103.045	-0.016	11.485
65	101.279	98.949	-1.424	10.009	265	101.280	98.949	-1.671	10.009	365	101.280	98.950	-1.492	10.009
66	not extracted				266	99.965	98.899	-1.672	10.008	366	99.965	98.900	-1.493	10.008
67	not extracted				267	101.327	99.918	-1.672	10.008	367	101.327	99.917	-1.493	10.008
68	100.068	105.614	-1.430	10.003	268	100.068	105.614	-1.676	10.004	368	not extracted			
69	101.019	105.607	-1.426	10.007	269	101.018	105.607	-1.673	10.007	369	not extracted			
70	not extracted				270	100.952	104.460	-1.677	10.003	370	not extracted			
1000	**100.005**	**100.063**	**0.000**	11.433	**2000**	**100.447**	**102.476**	**0.000**	11.680	**3000**	**100.667**	**104.348**	**0.000**	11.501

Step 4 - In this step the final table will be produced. Using Table 4.16, the average of all the Targets from each setup will be done. These coordinates will be compared to the signalized values and then any targets that have not fallen within the +-2mm tolerance will not be used further in the calibration. Refer to table 4.17

Table 4.17 Comparison of Final P20 scanner and signalized Target values

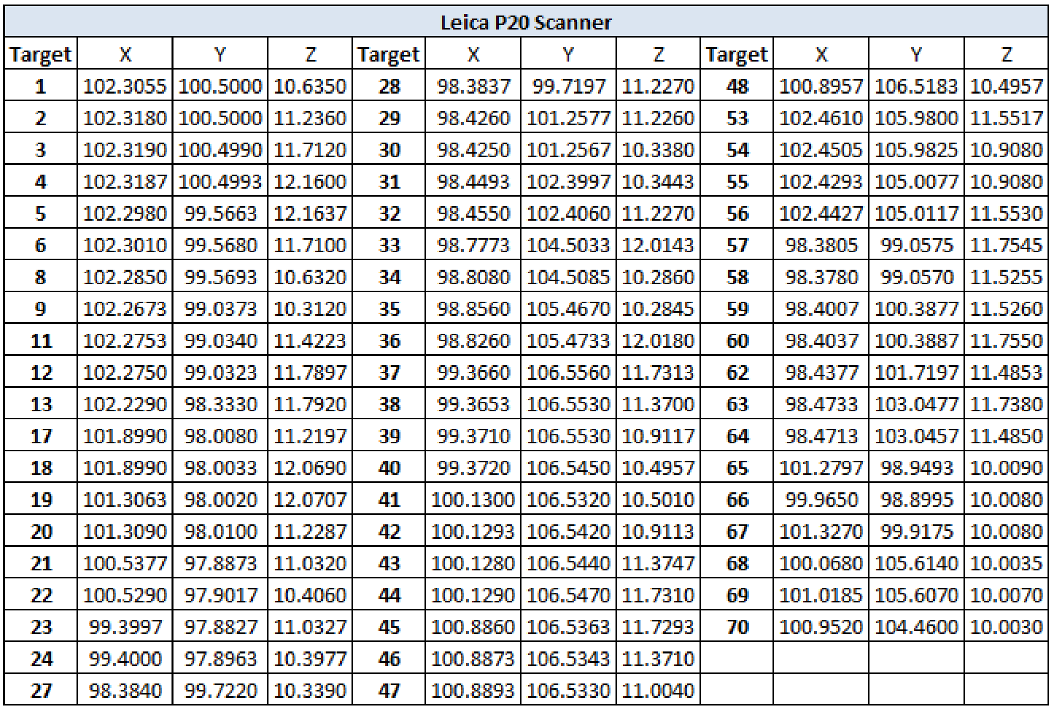


Leica P20 Scanner				SIGNALISED						
Target	X	Y	Z	Target	X	Y	Z	Diff X	Diff Y	Diff Z
1	102.3055	100.5000	10.6350	1	102.3050	100.5002	10.6352	0	0	0
2	102.3180	100.5000	11.2360	2	102.3180	100.5003	11.2355	0	0	0
3	102.3190	100.4990	11.7120	3	102.3192	100.4993	11.7117	0	0	0
4	102.3187	100.4993	12.1600	4	102.3197	100.4987	12.1597	-1	1	0
5	102.2980	99.5663	12.1637	5	102.2982	99.5660	12.1630	0	0	1
6	102.3010	99.5680	11.7100	6	102.3013	99.5675	11.7097	0	1	0
7	102.3013	99.5930	11.2250	7	102.3005	99.5688	11.2370	1	24	-12
8	102.2850	99.5693	10.6320	8	102.2842	99.5703	10.6320	1	-1	0
9	102.2673	99.0373	10.3120	9	102.2677	99.0365	10.3123	0	1	0
10	102.2790	99.0333	10.9897	10	102.2790	99.0332	10.9893	0	0	0
11	102.2753	99.0340	11.4223	11	102.2747	99.0343	11.4217	1	0	1
12	102.2750	99.0323	11.7897	12	102.2752	99.0317	11.7893	0	1	0
13	102.2290	98.3330	11.7920	13	102.2297	98.3325	11.7915	-1	1	1
14	102.2280	98.3325	11.4220	14	not signalised					
15	102.2290	98.3290	10.9890	15	102.2300	98.3295	10.9900	-1	-1	-1
16	102.2200	98.3310	10.3130	16	not signalised					
17	101.8990	98.0080	11.2197	17	101.8993	98.0077	11.2193	0	0	0
18	101.8990	98.0033	12.0690	18	101.8987	98.0028	12.0685	0	0	0
19	101.3063	98.0020	12.0707	19	101.3065	98.0013	12.0700	0	1	1
20	101.3090	98.0100	11.2287	20	101.3093	98.0100	11.2282	0	0	1
21	100.5377	97.8873	11.0320	21	100.5380	97.8862	11.0318	0	1	0
22	100.5290	97.9017	10.4060	22	100.5290	97.9022	10.4058	0	-1	0
23	99.3997	97.8827	11.0327	23	99.3992	97.8820	11.0323	1	1	0
24	99.4000	97.8963	10.3977	24	99.3998	97.8967	10.3980	0	0	0
25	98.3573	98.3787	11.2143	25	98.3547	98.4017	11.2257	3	-23	-11
26	98.3573	98.4037	10.3387	26	not signalised					
27	98.3840	99.7220	10.3390	27	98.3835	99.7210	10.3385	1	1	1
28	98.3837	99.7197	11.2270	28	98.3825	99.7193	11.2263	1	0	1
29	98.4260	101.2577	11.2260	29	98.4255	101.2578	11.2255	1	0	0
30	98.4250	101.2567	10.3380	30	98.4252	101.2558	10.3382	0	1	0
31	98.4493	102.3997	10.3443	31	98.4488	102.3997	10.3447	1	0	0
32	98.4550	102.4060	11.2270	32	98.4533	102.4067	11.2267	2	-1	0
33	98.7773	104.5033	12.0143	33	98.7760	104.5040	12.0135	1	-1	1
34	98.8080	104.5085	10.2860	34	98.8082	104.5088	10.2862	0	0	0
35	98.8560	105.4670	10.2845	35	98.8567	105.4672	10.2853	-1	0	-1
36	98.8260	105.4733	12.0180	36	98.8258	105.4742	12.0185	0	-1	0
37	99.3660	106.5560	11.7313	37	99.3657	106.5565	11.7317	0	-1	0
38	99.3653	106.5530	11.3700	38	99.3653	106.5528	11.3703	0	0	0
39	99.3710	106.5530	10.9117	39	99.3703	106.5533	10.9122	1	0	-1
40	99.3720	106.5450	10.4957	40	99.3720	106.5443	10.4960	0	1	0
41	100.1300	106.5320	10.5010	41	100.1297	106.5318	10.5018	0	0	-1
42	100.1293	106.5420	10.9113	42	100.1290	106.5422	10.9115	0	0	0
43	100.1280	106.5440	11.3747	43	100.1280	106.5440	11.3745	0	0	0
44	100.1290	106.5470	11.7310	44	100.1285	106.5470	11.7312	1	0	0
45	100.8860	106.5363	11.7293	45	100.8857	106.5357	11.7290	0	1	0
46	100.8873	106.5343	11.3710	46	100.8872	106.5335	11.3702	0	1	1
47	100.8893	106.5330	11.0040	47	100.8892	106.5322	11.0033	0	1	1
48	100.8957	106.5183	10.4957	48	100.8952	106.5165	10.4952	1	2	1
49	101.6413	106.4940	10.4960	49	not signalised					
50	101.6397	106.5020	11.0020	50	not signalised					
51	101.6417	106.5070	11.3690	51	not signalised					
52	101.6443	106.5083	11.7330	52	not signalised					
53	102.4610	105.9800	11.5517	53	102.4602	105.9803	11.5512	1	0	1
54	102.4505	105.9825	10.9080	54	102.4498	105.9830	10.9077	1	-1	0
55	102.4293	105.0077	10.9080	55	102.4283	105.0077	10.9083	1	0	0
56	102.4427	105.0117	11.5530	56	102.4412	105.0118	11.5530	1	0	0
57	98.3805	99.0575	11.7545	57	98.3802	99.0572	11.7543	0	0	0
58	98.3780	99.0570	11.5255	58	98.3772	99.0563	11.5247	1	1	1
59	98.4007	100.3877	11.5260	59	98.4007	100.3875	11.5248	0	0	1
60	98.4037	100.3887	11.7550	60	98.4025	100.3885	11.7545	1	0	1
61	98.4410	101.7213	11.7387	61	not signalised					
62	98.4377	101.7197	11.4853	62	98.4363	101.7197	11.4857	1	0	0
63	98.4733	103.0477	11.7380	63	98.4733	103.0470	11.7377	0	1	0
64	98.4713	103.0457	11.4850	64	98.4720	103.0457	11.4843	-1	0	1
65	101.2797	98.9493	10.0090	65	101.2800	98.9493	10.0087	0	0	0
66	99.9650	98.8995	10.0080	66	99.9648	98.8990	10.0080	0	1	0
67	101.3270	99.9175	10.0080	67	101.3270	99.9177	10.0067	0	0	1
68	100.0680	105.6140	10.0035	68	100.0680	105.6143	10.0045	0	0	-1
69	101.0185	105.6070	10.0070	69	101.0188	105.6080	10.0073	0	-1	0
70	100.9520	104.4600	10.0030	70	100.9520	104.4607	10.0032	0	-1	0

From Table 4.17 target 7 and 25 have fallen extremely out of tolerance (24mm), this cannot be explained but will be analysed further when the reductions of the faro Scanner are done. These two targets will not be used further in the calibration calculations. 97% of all targets scanned from three different setups have fallen within the +- 2mm tolerance this is an excellent result. Scanned Targets 14, 16, 26, 49-52 and 61 will also not be used as these targets were not signalised by the STS's. This leaves a Total of 60 targets to use in the calibration. Further to this there is one more independent check remaining to compare the measured joins with the new coordinates shown Table 4.17. This final calculation discovered the join between target 10 and 15 was out of tolerance (3mm) so these two targets were discarded. This gives a new Total of 58 Targets for calibration.

Now Table 4.18 is the final table showing the Scanned targets to used in the calibration.

Table 4.18 Final P20 Scanned Target Coordinates



Leica P20 Scanner											
Target	X	Y	Z	**Target**	X	Y	Z	**Target**	X	Y	Z
1	102.3055	100.5000	10.6350	**28**	98.3837	99.7197	11.2270	**48**	100.8957	106.5183	10.4957
2	102.3180	100.5000	11.2360	**29**	98.4260	101.2577	11.2260	**53**	102.4610	105.9800	11.5517
3	102.3190	100.4990	11.7120	**30**	98.4250	101.2567	10.3380	**54**	102.4505	105.9825	10.9080
4	102.3187	100.4993	12.1600	**31**	98.4493	102.3997	10.3443	**55**	102.4293	105.0077	10.9080
5	102.2980	99.5663	12.1637	**32**	98.4550	102.4060	11.2270	**56**	102.4427	105.0117	11.5530
6	102.3010	99.5680	11.7100	**33**	98.7773	104.5033	12.0143	**57**	98.3805	99.0575	11.7545
8	102.2850	99.5693	10.6320	**34**	98.8080	104.5085	10.2860	**58**	98.3780	99.0570	11.5255
9	102.2673	99.0373	10.3120	**35**	98.8560	105.4670	10.2845	**59**	98.4007	100.3877	11.5260
11	102.2753	99.0340	11.4223	**36**	98.8260	105.4733	12.0180	**60**	98.4037	100.3887	11.7550
12	102.2750	99.0323	11.7897	**37**	99.3660	106.5560	11.7313	**62**	98.4377	101.7197	11.4853
13	102.2290	98.3330	11.7920	**38**	99.3653	106.5530	11.3700	**63**	98.4733	103.0477	11.7380
17	101.8990	98.0080	11.2197	**39**	99.3710	106.5530	10.9117	**64**	98.4713	103.0457	11.4850
18	101.8990	98.0033	12.0690	**40**	99.3720	106.5450	10.4957	**65**	101.2797	98.9493	10.0090
19	101.3063	98.0020	12.0707	**41**	100.1300	106.5320	10.5010	**66**	99.9650	98.8995	10.0080
20	101.3090	98.0100	11.2287	**42**	100.1293	106.5420	10.9113	**67**	101.3270	99.9175	10.0080
21	100.5377	97.8873	11.0320	**43**	100.1280	106.5440	11.3747	**68**	100.0680	105.6140	10.0035
22	100.5290	97.9017	10.4060	**44**	100.1290	106.5470	11.7310	**69**	101.0185	105.6070	10.0070
23	99.3997	97.8827	11.0327	**45**	100.8860	106.5363	11.7293	**70**	100.9520	104.4600	10.0030
24	99.4000	97.8963	10.3977	**46**	100.8873	106.5343	11.3710				
27	98.3840	99.7220	10.3390	**47**	100.8893	106.5330	11.0040				

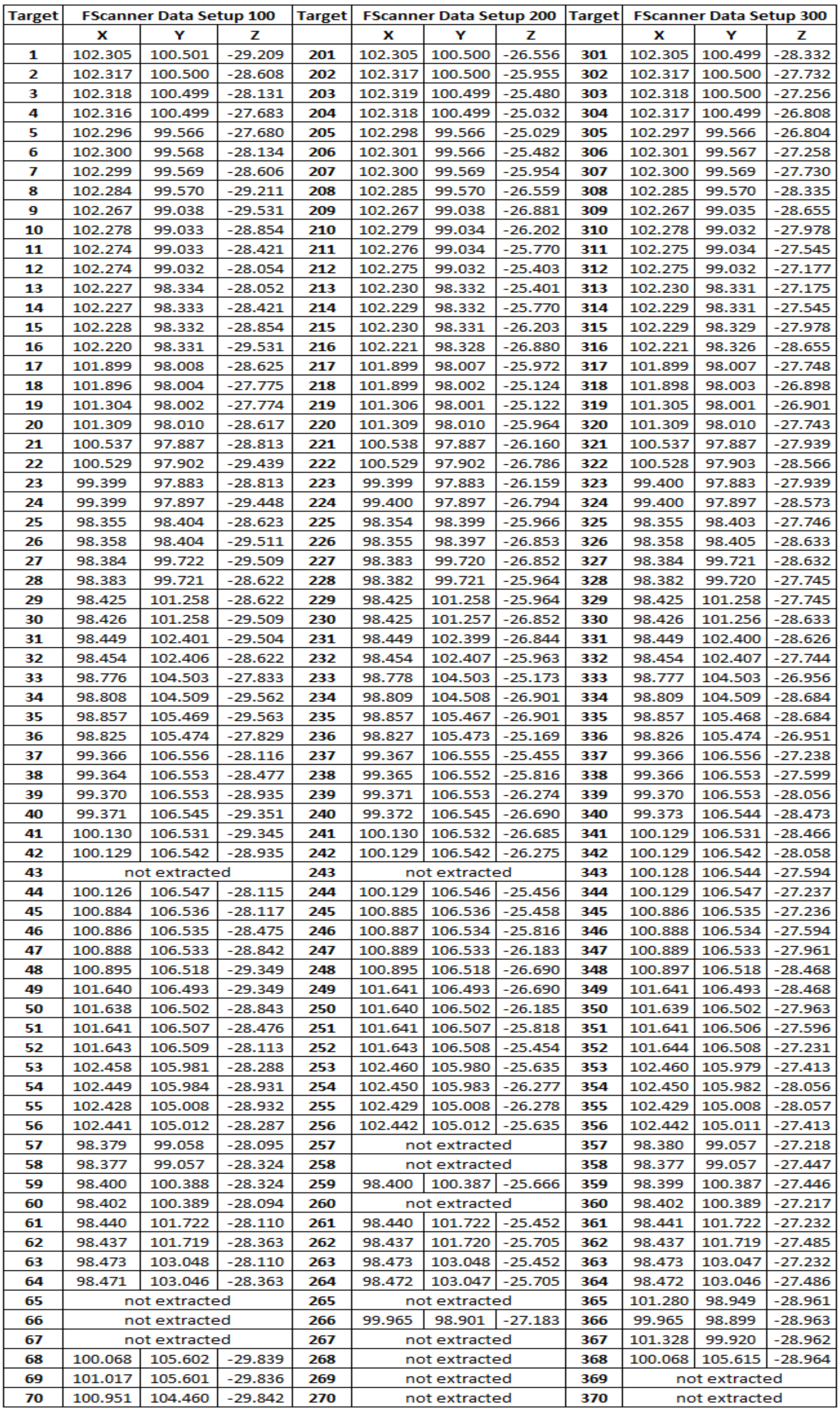
4.3.2 Stage 2 Faro Focus 3D X330

Step 1 - Transformation of the three scanner data sets using three points. The transformation of the Leica P20 scanner data used targets 20, 29 and 43. Unfortunately target 43 could not be extracted from the point cloud hence 42 was used. The incident angles, height above ground and general placement position within the calibration space of these three targets aided in their selection. It is important to note the P20 scanner data were re-transformed using base point target 20, 29, and 42 and exactly the same results were produced. The original transformation using base points 20, 29, and 43 will be used in the project as changing from Target 42 to 43 in the transformation had no impact to the results.

The raw target centroids were exported from the Faro SCENE 5.5 software as a text file. This data was put in order of Point Number, Easting, Northing and Elevation and imported into CivilCad 7.0 individually and not as a bundle, for transformation. This was done for all three scanner data sets. During the transformation the residuals were zero. Once transformed the scanner data was exported as a txt file and imported into an excel spreadsheet for comparison.

Step 2 - Table 4.19 shows the XYZ values for each target

Table 4.19 The Faro transformed scanner target centroids



Target	FScanner Data Setup 100			Target	FScanner Data Setup 200			Target	FScanner Data Setup 300		
	X	Y	Z		X	Y	Z		X	Y	Z
1	102.305	100.501	-29.209	**201**	102.305	100.500	-26.556	**301**	102.305	100.499	-28.332
2	102.317	100.500	-28.608	**202**	102.317	100.500	-25.955	**302**	102.317	100.500	-27.732
3	102.318	100.499	-28.131	**203**	102.319	100.499	-25.480	**303**	102.318	100.500	-27.256
4	102.316	100.499	-27.683	**204**	102.318	100.499	-25.032	**304**	102.317	100.499	-26.808
5	102.296	99.566	-27.680	**205**	102.298	99.566	-25.029	**305**	102.297	99.566	-26.804
6	102.300	99.568	-28.134	**206**	102.301	99.566	-25.482	**306**	102.301	99.567	-27.258
7	102.299	99.569	-28.606	**207**	102.300	99.569	-25.954	**307**	102.300	99.569	-27.730
8	102.284	99.570	-29.211	**208**	102.285	99.570	-26.559	**308**	102.285	99.570	-28.335
9	102.267	99.038	-29.531	**209**	102.267	99.038	-26.881	**309**	102.267	99.035	-28.655
10	102.278	99.033	-28.854	**210**	102.279	99.034	-26.202	**310**	102.278	99.032	-27.978
11	102.274	99.033	-28.421	**211**	102.276	99.034	-25.770	**311**	102.275	99.034	-27.545
12	102.274	99.032	-28.054	**212**	102.275	99.032	-25.403	**312**	102.275	99.032	-27.177
13	102.227	98.334	-28.052	**213**	102.230	98.332	-25.401	**313**	102.230	98.331	-27.175
14	102.227	98.333	-28.421	**214**	102.229	98.332	-25.770	**314**	102.229	98.331	-27.545
15	102.228	98.332	-28.854	**215**	102.230	98.331	-26.203	**315**	102.229	98.329	-27.978
16	102.220	98.331	-29.531	**216**	102.221	98.328	-26.880	**316**	102.221	98.326	-28.655
17	101.899	98.008	-28.625	**217**	101.899	98.007	-25.972	**317**	101.899	98.007	-27.748
18	101.896	98.004	-27.775	**218**	101.899	98.002	-25.124	**318**	101.898	98.003	-26.898
19	101.304	98.002	-27.774	**219**	101.306	98.001	-25.122	**319**	101.305	98.001	-26.901
20	101.309	98.010	-28.617	**220**	101.309	98.010	-25.964	**320**	101.309	98.010	-27.743
21	100.537	97.887	-28.813	**221**	100.538	97.887	-26.160	**321**	100.537	97.887	-27.939
22	100.529	97.902	-29.439	**222**	100.529	97.902	-26.786	**322**	100.528	97.903	-28.566
23	99.399	97.883	-28.813	**223**	99.399	97.883	-26.159	**323**	99.400	97.883	-27.939
24	99.399	97.897	-29.448	**224**	99.400	97.897	-26.794	**324**	99.400	97.897	-28.573
25	98.355	98.404	-28.623	**225**	98.354	98.399	-25.966	**325**	98.355	98.403	-27.746
26	98.358	98.404	-29.511	**226**	98.355	98.397	-26.853	**326**	98.358	98.405	-28.633
27	98.384	99.722	-29.509	**227**	98.383	99.720	-26.852	**327**	98.384	99.721	-28.632
28	98.383	99.721	-28.622	**228**	98.382	99.721	-25.964	**328**	98.382	99.720	-27.745
29	98.425	101.258	-28.622	**229**	98.425	101.258	-25.964	**329**	98.425	101.258	-27.745
30	98.426	101.258	-29.509	**230**	98.425	101.257	-26.852	**330**	98.426	101.256	-28.633
31	98.449	102.401	-29.504	**231**	98.449	102.399	-26.844	**331**	98.449	102.400	-28.626
32	98.454	102.406	-28.622	**232**	98.454	102.407	-25.963	**332**	98.454	102.407	-27.744
33	98.776	104.503	-27.833	**233**	98.778	104.503	-25.173	**333**	98.777	104.503	-26.956
34	98.808	104.509	-29.562	**234**	98.809	104.508	-26.901	**334**	98.809	104.509	-28.684
35	98.857	105.469	-29.563	**235**	98.857	105.467	-26.901	**335**	98.857	105.468	-28.684
36	98.825	105.474	-27.829	**236**	98.827	105.473	-25.169	**336**	98.826	105.474	-26.951
37	99.366	106.556	-28.116	**237**	99.367	106.555	-25.455	**337**	99.366	106.556	-27.238
38	99.364	106.553	-28.477	**238**	99.365	106.552	-25.816	**338**	99.366	106.553	-27.599
39	99.370	106.553	-28.935	**239**	99.371	106.553	-26.274	**339**	99.370	106.553	-28.056
40	99.371	106.545	-29.351	**240**	99.372	106.545	-26.690	**340**	99.373	106.544	-28.473
41	100.130	106.531	-29.345	**241**	100.130	106.532	-26.685	**341**	100.129	106.531	-28.466
42	100.129	106.542	-28.935	**242**	100.129	106.542	-26.275	**342**	100.129	106.542	-28.058
43	not extracted			**243**	not extracted			**343**	100.128	106.544	-27.594
44	100.126	106.547	-28.115	**244**	100.129	106.546	-25.456	**344**	100.129	106.547	-27.237
45	100.884	106.536	-28.117	**245**	100.885	106.536	-25.458	**345**	100.886	106.535	-27.236
46	100.886	106.535	-28.475	**246**	100.887	106.534	-25.816	**346**	100.888	106.534	-27.594
47	100.888	106.533	-28.842	**247**	100.889	106.533	-26.183	**347**	100.889	106.533	-27.961
48	100.895	106.518	-29.349	**248**	100.895	106.518	-26.690	**348**	100.897	106.518	-28.468
49	101.640	106.493	-29.349	**249**	101.641	106.493	-26.690	**349**	101.641	106.493	-28.468
50	101.638	106.502	-28.843	**250**	101.640	106.502	-26.185	**350**	101.639	106.502	-27.963
51	101.641	106.507	-28.476	**251**	101.641	106.507	-25.818	**351**	101.641	106.506	-27.596
52	101.643	106.509	-28.113	**252**	101.643	106.508	-25.454	**352**	101.644	106.508	-27.231
53	102.458	105.981	-28.288	**253**	102.460	105.980	-25.635	**353**	102.460	105.979	-27.413
54	102.449	105.984	-28.931	**254**	102.450	105.983	-26.277	**354**	102.450	105.982	-28.056
55	102.428	105.008	-28.932	**255**	102.429	105.008	-26.278	**355**	102.429	105.008	-28.057
56	102.441	105.012	-28.287	**256**	102.442	105.012	-25.635	**356**	102.442	105.011	-27.413
57	98.379	99.058	-28.095	**257**	not extracted			**357**	98.380	99.057	-27.218
58	98.377	99.057	-28.324	**258**	not extracted			**358**	98.377	99.057	-27.447
59	98.400	100.388	-28.324	**259**	98.400	100.387	-25.666	**359**	98.399	100.387	-27.446
60	98.402	100.389	-28.094	**260**	not extracted			**360**	98.402	100.389	-27.217
61	98.440	101.722	-28.110	**261**	98.440	101.722	-25.452	**361**	98.441	101.722	-27.232
62	98.437	101.719	-28.363	**262**	98.437	101.720	-25.705	**362**	98.437	101.719	-27.485
63	98.473	103.048	-28.110	**263**	98.473	103.048	-25.452	**363**	98.473	103.047	-27.232
64	98.471	103.046	-28.363	**264**	98.472	103.047	-25.705	**364**	98.472	103.046	-27.486
65	not extracted			**265**	not extracted			**365**	101.280	98.949	-28.961
66	not extracted			**266**	99.965	98.901	-27.183	**366**	99.965	98.899	-28.963
67	not extracted			**267**	not extracted			**367**	101.328	99.920	-28.962
68	100.068	105.602	-29.839	**268**	not extracted			**368**	100.068	105.615	-28.964
69	101.017	105.601	-29.836	**269**	not extracted			**369**	not extracted		
70	100.951	104.460	-29.842	**270**	not extracted			**370**	not extracted		

Targets that were scanned but not extracted in the point cloud, are noted in the table. Figure 4.7 shows an example of why a target could not be extracted, in this case the brightness of the light diminished the black and white checker pattern Target 43 at setup 200 (a) and from setup 200 the horizontal angel from the scanner to targets 57, 58 and 60 were no good(b).

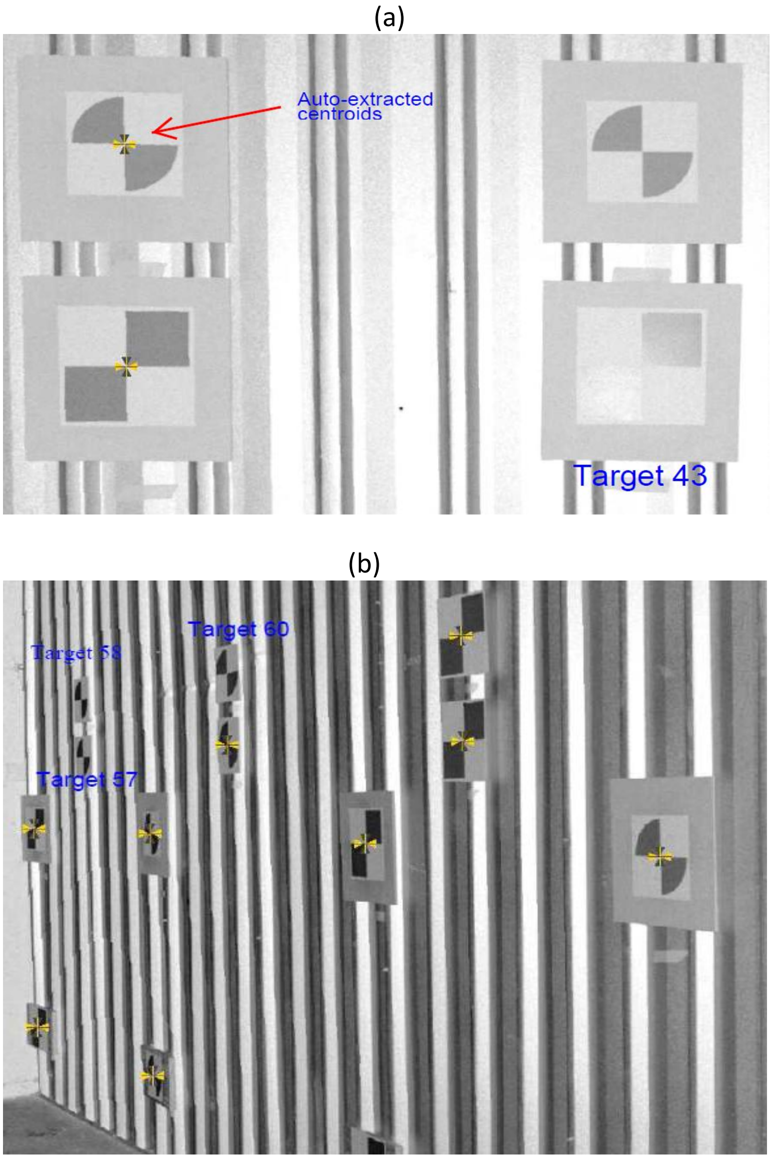


Figure 4.7 Targets not extracted from point cloud

Step 2 - Table 4.19 showed the XYZ values for each target . The Z values have not been transformed to ground values. This will be done by calculating the difference between the true target elevation and the scanner target elevation. This should be the same value for all the targets from that setup. If there is a variation in the difference of +- 2mm then the average will be calculated and adopted.

For setup 100,the value of 39.844 need to be added to all the Z values to have ground elevations.

Signalised Target RL - Scanner Target RL = Difference in RL (Constant)

$$10.635-\left(-29.209\right)=39.844$$

For setup 200,the value of 37.191 need to be added to all the Z values to have ground elevations.

Signalised Target RL - Scanner Target RL = Difference in RL (Constant)

$$10.635-\left(-26.556\right)=37.191$$

For setup 300 it is 38.967.

Signalised Target RL - Scanner Target RL = Difference in RL (Constant)

$$10.635-\left(-28.332\right)=38.967$$

The constants from each setup have been checked by reversing the calculation to be :

(the scanner target RL - calculated Z value of that target = constant)

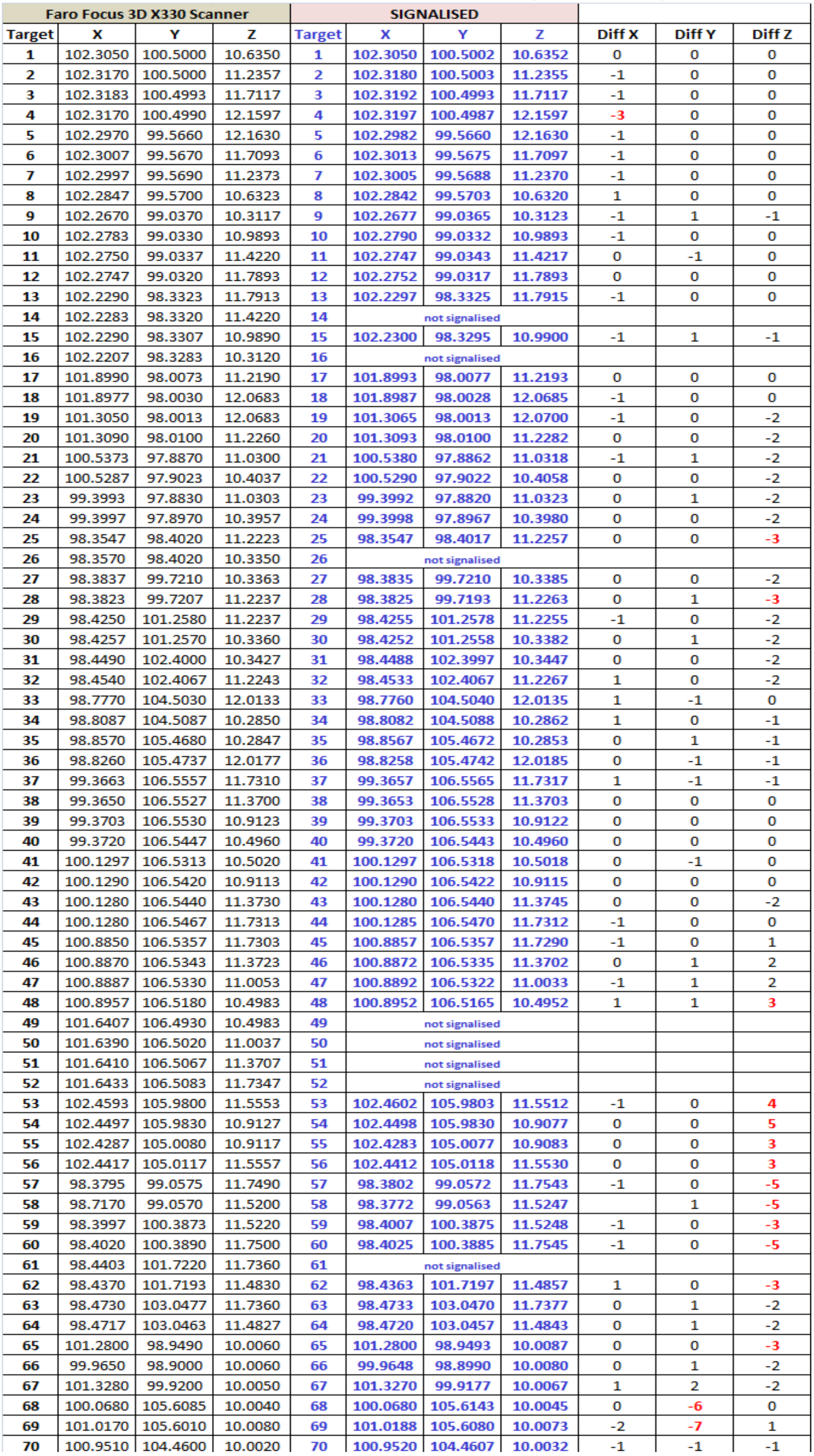
Table 4.20 shows the final scanner target centroids with the adjusted heights as well.

Table 4.20 Final Scanner target centroids coordinated to the indoor calibration System.

FScanner Data Setup 100					FScanner Data Setup 200					FScanner Data Setup 300				
Target	**X**	**Y**		**Z**	**Target**	**X**	**Y**		**Z**	**Target**	**X**	**Y**		**Z**
1	102.305	100.501	-29.209	**10.635**	**201**	102.305	100.500	-26.556	**10.635**	**301**	102.305	100.499	-28.332	**10.635**
2	102.317	100.500	-28.608	**11.236**	**202**	102.317	100.500	-25.955	**11.236**	**302**	102.317	100.500	-27.732	**11.235**
3	102.318	100.499	-28.131	**11.713**	**203**	102.319	100.499	-25.480	**11.711**	**303**	102.318	100.500	-27.256	**11.711**
4	102.316	100.499	-27.683	**12.161**	**204**	102.318	100.499	-25.032	**12.159**	**304**	102.317	100.499	-26.808	**12.159**
5	102.296	99.566	-27.680	**12.164**	**205**	102.298	99.566	-25.029	**12.162**	**305**	102.297	99.566	-26.804	**12.163**
6	102.300	99.568	-28.134	**11.710**	**206**	102.301	99.566	-25.482	**11.709**	**306**	102.301	99.567	-27.258	**11.709**
7	102.299	99.569	-28.606	**11.238**	**207**	102.300	99.569	-25.954	**11.237**	**307**	102.300	99.569	-27.730	**11.237**
8	102.284	99.570	-29.211	**10.633**	**208**	102.285	99.570	-26.559	**10.632**	**308**	102.285	99.570	-28.335	**10.632**
9	102.267	99.038	-29.531	**10.313**	**209**	102.267	99.038	-26.881	**10.310**	**309**	102.267	99.035	-28.655	**10.312**
10	102.278	99.033	-28.854	**10.990**	**210**	102.279	99.034	-26.202	**10.989**	**310**	102.278	99.032	-27.978	**10.989**
11	102.274	99.033	-28.421	**11.423**	**211**	102.276	99.034	-25.770	**11.421**	**311**	102.275	99.034	-27.545	**11.422**
12	102.274	99.032	-28.054	**11.790**	**212**	102.275	99.032	-25.403	**11.788**	**312**	102.275	99.032	-27.177	**11.790**
13	102.227	98.334	-28.052	**11.792**	**213**	102.230	98.332	-25.401	**11.790**	**313**	102.230	98.331	-27.175	**11.792**
14	102.227	98.333	-28.421	**11.423**	**214**	102.229	98.332	-25.770	**11.421**	**314**	102.229	98.331	-27.545	**11.422**
15	102.228	98.332	-28.854	**10.990**	**215**	102.230	98.331	-26.203	**10.988**	**315**	102.229	98.329	-27.978	**10.989**
16	102.220	98.331	-29.531	**10.313**	**216**	102.221	98.328	-26.880	**10.311**	**316**	102.221	98.326	-28.655	**10.312**
17	101.899	98.008	-28.625	**11.219**	**217**	101.899	98.007	-25.972	**11.219**	**317**	101.899	98.007	-27.748	**11.219**
18	101.896	98.004	-27.775	**12.069**	**218**	101.899	98.002	-25.124	**12.067**	**318**	101.898	98.003	-26.898	**12.069**
19	101.304	98.002	-27.774	**12.070**	**219**	101.306	98.001	-25.122	**12.069**	**319**	101.305	98.001	-26.901	**12.066**
20	101.309	98.010	-28.617	**11.227**	**220**	101.309	98.010	-25.964	**11.227**	**320**	101.309	98.010	-27.743	**11.224**
21	100.537	97.887	-28.813	**11.031**	**221**	100.538	97.887	-26.160	**11.031**	**321**	100.537	97.887	-27.939	**11.028**
22	100.529	97.902	-29.439	**10.405**	**222**	100.529	97.902	-26.786	**10.405**	**322**	100.528	97.903	-28.566	**10.401**
23	99.399	97.883	-28.813	**11.031**	**223**	99.399	97.883	-26.159	**11.032**	**323**	99.400	97.883	-27.939	**11.028**
24	99.399	97.897	-29.448	**10.396**	**224**	99.400	97.897	-26.794	**10.397**	**324**	99.400	97.897	-28.573	**10.394**
25	98.355	98.404	-28.623	**11.221**	**225**	98.354	98.399	-25.966	**11.225**	**325**	98.355	98.403	-27.746	**11.221**
26	98.358	98.404	-29.511	**10.333**	**226**	98.355	98.397	-26.853	**10.338**	**326**	98.358	98.405	-28.633	**10.334**
27	98.384	99.722	-29.509	**10.335**	**227**	98.383	99.720	-26.852	**10.339**	**327**	98.384	99.721	-28.632	**10.335**
28	98.383	99.721	-28.622	**11.222**	**228**	98.382	99.721	-25.964	**11.227**	**328**	98.382	99.720	-27.745	**11.222**
29	98.425	101.258	-28.622	**11.222**	**229**	98.425	101.258	-25.964	**11.227**	**329**	98.425	101.258	-27.745	**11.222**
30	98.426	101.258	-29.509	**10.335**	**230**	98.425	101.257	-26.852	**10.339**	**330**	98.426	101.256	-28.633	**10.334**
31	98.449	102.401	-29.504	**10.340**	**231**	98.449	102.399	-26.844	**10.347**	**331**	98.449	102.400	-28.626	**10.341**
32	98.454	102.406	-28.622	**11.222**	**232**	98.454	102.407	-25.963	**11.228**	**332**	98.454	102.407	-27.744	**11.223**
33	98.776	104.503	-27.833	**12.011**	**233**	98.778	104.503	-25.173	**12.018**	**333**	98.777	104.503	-26.956	**12.011**
34	98.808	104.509	-29.562	**10.282**	**234**	98.809	104.508	-26.901	**10.290**	**334**	98.809	104.509	-28.684	**10.283**
35	98.857	105.469	-29.563	**10.281**	**235**	98.857	105.467	-26.901	**10.290**	**335**	98.857	105.468	-28.684	**10.283**
36	98.825	105.474	-27.829	**12.015**	**236**	98.827	105.473	-25.169	**12.022**	**336**	98.826	105.474	-26.951	**12.016**
37	99.366	106.556	-28.116	**11.728**	**237**	99.367	106.555	-25.455	**11.736**	**337**	99.366	106.556	-27.238	**11.729**
38	99.364	106.553	-28.477	**11.367**	**238**	99.365	106.552	-25.816	**11.375**	**338**	99.366	106.553	-27.599	**11.368**
39	99.370	106.553	-28.935	**10.909**	**239**	99.371	106.553	-26.274	**10.917**	**339**	99.370	106.553	-28.056	**10.911**
40	99.371	106.545	-29.351	**10.493**	**240**	99.372	106.545	-26.690	**10.501**	**340**	99.373	106.544	-28.473	**10.494**
41	100.130	106.531	-29.345	**10.499**	**241**	100.130	106.532	-26.685	**10.506**	**341**	100.129	106.531	-28.466	**10.501**
42	100.129	106.542	-28.935	**10.909**	**242**	100.129	106.542	-26.275	**10.916**	**342**	100.129	106.542	-28.058	**10.909**
43	not extracted				**243**	not extracted				**343**	100.128	106.544	-27.594	**11.373**
44	100.126	106.547	-28.115	**11.729**	**244**	100.129	106.546	-25.456	**11.735**	**344**	100.129	106.547	-27.237	**11.730**
45	100.884	106.536	-28.117	**11.727**	**245**	100.885	106.536	-25.458	**11.733**	**345**	100.886	106.535	-27.236	**11.731**
46	100.886	106.535	-28.475	**11.369**	**246**	100.887	106.534	-25.816	**11.375**	**346**	100.888	106.534	-27.594	**11.373**
47	100.888	106.533	-28.842	**11.002**	**247**	100.889	106.533	-26.183	**11.008**	**347**	100.889	106.533	-27.961	**11.006**
48	100.895	106.518	-29.349	**10.495**	**248**	100.895	106.518	-26.690	**10.501**	**348**	100.897	106.518	-28.468	**10.499**
49	101.640	106.493	-29.349	**10.495**	**249**	101.641	106.493	-26.690	**10.501**	**349**	101.641	106.493	-28.468	**10.499**
50	101.638	106.502	-28.843	**11.001**	**250**	101.640	106.502	-26.185	**11.006**	**350**	101.639	106.502	-27.963	**11.004**
51	101.641	106.507	-28.476	**11.368**	**251**	101.641	106.507	-25.818	**11.373**	**351**	101.641	106.506	-27.596	**11.371**
52	101.643	106.509	-28.113	**11.731**	**252**	101.643	106.508	-25.454	**11.737**	**352**	101.644	106.508	-27.231	**11.736**
53	102.458	105.981	-28.288	**11.556**	**253**	102.460	105.980	-25.635	**11.556**	**353**	102.460	105.979	-27.413	**11.554**
54	102.449	105.984	-28.931	**10.913**	**254**	102.450	105.983	-26.277	**10.914**	**354**	102.450	105.982	-28.056	**10.911**
55	102.428	105.008	-28.932	**10.912**	**255**	102.429	105.008	-26.278	**10.913**	**355**	102.429	105.008	-28.057	**10.910**
56	102.441	105.012	-28.287	**11.557**	**256**	102.442	105.012	-25.635	**11.556**	**356**	102.442	105.011	-27.413	**11.554**
57	98.379	99.058	-28.095	**11.749**	**257**	not extracted				**357**	98.380	99.057	-27.218	**11.749**
58	98.377	99.057	-28.324	**11.520**	**258**	not extracted				**358**	98.377	99.057	-27.447	**11.520**
59	98.400	100.388	-28.324	**11.520**	**259**	98.400	100.387	-25.666	**11.525**	**359**	98.399	100.387	-27.446	**11.521**
60	98.402	100.389	-28.094	**11.750**	**260**	not extracted				**360**	98.402	100.389	-27.217	**11.750**
61	98.440	101.722	-28.110	**11.734**	**261**	98.440	101.722	-25.452	**11.739**	**361**	98.441	101.722	-27.232	**11.735**
62	98.437	101.719	-28.363	**11.481**	**262**	98.437	101.720	-25.705	**11.486**	**362**	98.437	101.719	-27.485	**11.482**
63	98.473	103.048	-28.110	**11.734**	**263**	98.473	103.048	-25.452	**11.739**	**363**	98.473	103.047	-27.232	**11.735**
64	98.471	103.046	-28.363	**11.481**	**264**	98.472	103.047	-25.705	**11.486**	**364**	98.472	103.046	-27.486	**11.481**
65	not extracted				**265**	not extracted				**365**	101.280	98.949	-28.961	**10.006**
66	not extracted				**266**	99.965	98.901	-27.183	**10.008**	**366**	99.965	98.899	-28.963	**10.004**
67	not extracted				**267**	not extracted				**367**	101.328	99.920	-28.962	**10.005**
68	100.068	105.602	-29.839	**10.005**	**268**	not extracted				**368**	100.068	105.615	-28.964	**10.003**
69	101.017	105.601	-29.836	**10.008**	**269**	not extracted				**369**	not extracted			
70	100.951	104.460	-29.842	**10.002**	**270**	not extracted				**370**	not extracted			

Step 3 - In this step the final table will be produced. Using Table 4.20, the average of all the Targets from each setup will be done. These coordinates will be compared to the signalized values and then any targets that have not fallen within the +-2mm tolerance, will not be used further in the calibration. Refer to table 4.21

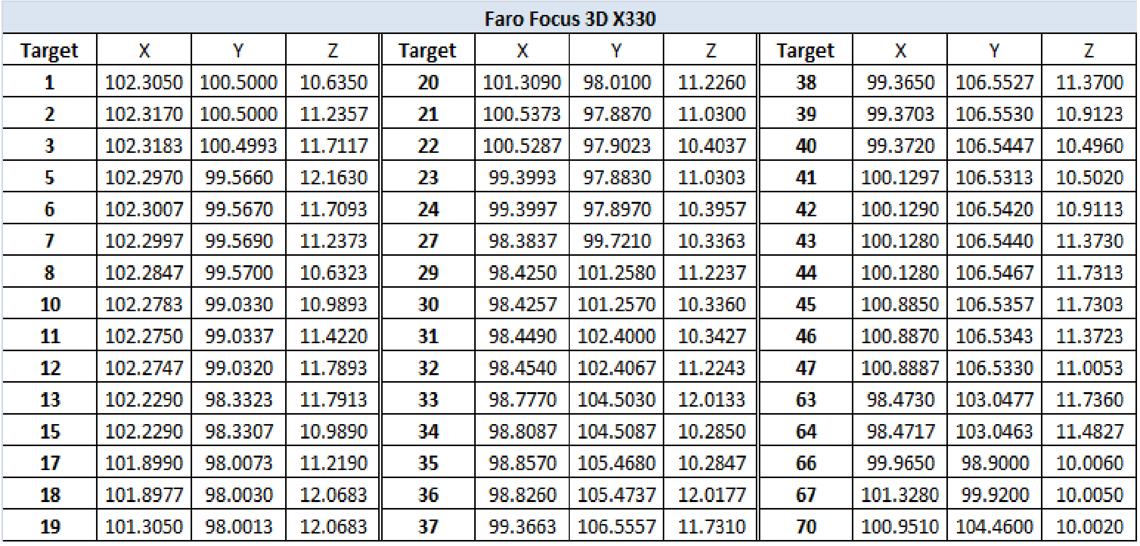
Table 4.21 Comparison of Final scanner and signalized Target values



Faro Focus 3D X330 Scanner				SIGNALISED						
Target	**X**	**Y**	**Z**	Target	X	Y	Z	**Diff X**	**Diff Y**	**Diff Z**
1	102.3050	100.5000	10.6350	1	102.3050	100.5002	10.6352	0	0	0
2	102.3170	100.5000	11.2357	2	102.3180	100.5003	11.2355	-1	0	0
3	102.3183	100.4993	11.7117	3	102.3192	100.4993	11.7117	-1	0	0
4	102.3170	100.4990	12.1597	4	102.3197	100.4987	12.1597	-3	0	0
5	102.2970	99.5660	12.1630	5	102.2982	99.5660	12.1630	-1	0	0
6	102.3007	99.5670	11.7093	6	102.3013	99.5675	11.7097	-1	0	0
7	102.2997	99.5690	11.2373	7	102.3005	99.5688	11.2370	-1	0	0
8	102.2847	99.5700	10.6323	8	102.2842	99.5703	10.6320	1	0	0
9	102.2670	99.0370	10.3117	9	102.2677	99.0365	10.3123	-1	1	-1
10	102.2783	99.0330	10.9893	10	102.2790	99.0332	10.9893	-1	0	0
11	102.2750	99.0337	11.4220	11	102.2747	99.0343	11.4217	0	-1	0
12	102.2747	99.0320	11.7893	12	102.2752	99.0317	11.7893	0	0	0
13	102.2290	98.3323	11.7913	13	102.2297	98.3325	11.7915	-1	0	0
14	102.2283	98.3320	11.4220	14	not signalised					
15	102.2290	98.3307	10.9890	15	102.2300	98.3295	10.9900	-1	1	-1
16	102.2207	98.3283	10.3120	16	not signalised					
17	101.8990	98.0073	11.2190	17	101.8993	98.0077	11.2193	0	0	0
18	101.8977	98.0030	12.0683	18	101.8987	98.0028	12.0685	-1	0	0
19	101.3050	98.0013	12.0683	19	101.3065	98.0013	12.0700	-1	0	-2
20	101.3090	98.0100	11.2260	20	101.3093	98.0100	11.2282	0	0	-2
21	100.5373	97.8870	11.0300	21	100.5380	97.8862	11.0318	-1	1	-2
22	100.5287	97.9023	10.4037	22	100.5290	97.9022	10.4058	0	0	-2
23	99.3993	97.8830	11.0303	23	99.3992	97.8820	11.0323	0	1	-2
24	99.3997	97.8970	10.3957	24	99.3998	97.8967	10.3980	0	0	-2
25	98.3547	98.4020	11.2223	25	98.3547	98.4017	11.2257	0	0	-3
26	98.3570	98.4020	10.3350	26	not signalised					
27	98.3837	99.7210	10.3363	27	98.3835	99.7210	10.3385	0	0	-2
28	98.3823	99.7207	11.2237	28	98.3825	99.7193	11.2263	0	1	-3
29	98.4250	101.2580	11.2237	29	98.4255	101.2578	11.2255	-1	0	-2
30	98.4257	101.2570	10.3360	30	98.4252	101.2558	10.3382	0	1	-2
31	98.4490	102.4000	10.3427	31	98.4488	102.3997	10.3447	0	0	-2
32	98.4540	102.4067	11.2243	32	98.4533	102.4067	11.2267	1	0	-2
33	98.7770	104.5030	12.0133	33	98.7760	104.5040	12.0135	1	-1	0
34	98.8087	104.5087	10.2850	34	98.8082	104.5088	10.2862	1	0	-1
35	98.8570	105.4680	10.2847	35	98.8567	105.4672	10.2853	0	1	-1
36	98.8260	105.4737	12.0177	36	98.8258	105.4742	12.0185	0	-1	-1
37	99.3663	106.5557	11.7310	37	99.3657	106.5565	11.7317	1	-1	-1
38	99.3650	106.5527	11.3700	38	99.3653	106.5528	11.3703	0	0	0
39	99.3703	106.5530	10.9123	39	99.3703	106.5533	10.9122	0	0	0
40	99.3720	106.5447	10.4960	40	99.3720	106.5443	10.4960	0	0	0
41	100.1297	106.5313	10.5020	41	100.1297	106.5318	10.5018	0	-1	0
42	100.1290	106.5420	10.9113	42	100.1290	106.5422	10.9115	0	0	0
43	100.1280	106.5440	11.3730	43	100.1280	106.5440	11.3745	0	0	-2
44	100.1280	106.5467	11.7313	44	100.1285	106.5470	11.7312	-1	0	0
45	100.8850	106.5357	11.7303	45	100.8857	106.5357	11.7290	-1	0	1
46	100.8870	106.5343	11.3723	46	100.8872	106.5335	11.3702	0	1	2
47	100.8887	106.5330	11.0053	47	100.8892	106.5322	11.0033	-1	1	2
48	100.8957	106.5180	10.4983	48	100.8952	106.5165	10.4952	1	1	3
49	101.6407	106.4930	10.4983	49	not signalised					
50	101.6390	106.5020	11.0037	50	not signalised					
51	101.6410	106.5067	11.3707	51	not signalised					
52	101.6433	106.5083	11.7347	52	not signalised					
53	102.4593	105.9800	11.5553	53	102.4602	105.9803	11.5512	-1	0	4
54	102.4497	105.9830	10.9127	54	102.4498	105.9830	10.9077	0	0	5
55	102.4287	105.0080	10.9117	55	102.4283	105.0077	10.9083	0	0	3
56	102.4417	105.0117	11.5557	56	102.4412	105.0118	11.5530	0	0	3
57	98.3795	99.0575	11.7490	57	98.3802	99.0572	11.7543	-1	0	-5
58	98.7170	99.0570	11.5200	58	98.3772	99.0563	11.5247		1	-5
59	98.3997	100.3873	11.5220	59	98.4007	100.3875	11.5248	-1	0	-3
60	98.4020	100.3890	11.7500	60	98.4025	100.3885	11.7545	-1	0	-5
61	98.4403	101.7220	11.7360	61	not signalised					
62	98.4370	101.7193	11.4830	62	98.4363	101.7197	11.4857	1	0	-3
63	98.4730	103.0477	11.7360	63	98.4733	103.0470	11.7377	0	1	-2
64	98.4717	103.0463	11.4827	64	98.4720	103.0457	11.4843	0	1	-2
65	101.2800	98.9490	10.0060	65	101.2800	98.9493	10.0087	0	0	-3
66	99.9650	98.9000	10.0060	66	99.9648	98.8990	10.0080	0	1	-2
67	101.3280	99.9200	10.0050	67	101.3270	99.9177	10.0067	1	2	-2
68	100.0680	105.6085	10.0040	68	100.0680	105.6143	10.0045	0	-6	0
69	101.0170	105.6010	10.0080	69	101.0188	105.6080	10.0073	-2	-7	1
70	100.9510	104.4600	10.0020	70	100.9520	104.4607	10.0032	-1	-1	-1

Step 4 - From Table 4.21 target's 4, 25, 28, 48, 53-60, 62, 65, 68 and 69 have fallen out of tolerance, this cannot be explained but will be analysed further. These targets will not be used further in the calibration calculations. 77% of all targets scanned from three different setups have fallen within the +- 2mm tolerance this is an excellent result. Scanned Targets 14, 16, 26, 49-52 and 61 will also not be used as these targets were not signalised by the STS's. This leaves a Total of 46 targets to use in the calibration. Further to this there is one more independent check remaining to compare the measured joins with the new coordinates from Table 4.121. This final calculation discovered the join between targets 58-59, 9-16, 61-62, 25-28 and 51-50 are out of tolerance so these targets will be discarded. This gives a new Total of 45 Targets for calibration. Now Table 4.22 the final reductions Table will be produced showing Scanned targets to used in the calibration.

Table 4.22 Final Faro Focus 3D X330 Scanned Target Coordinates



Faro Focus 3D X330											
Target	X	Y	Z	**Target**	X	Y	Z	**Target**	X	Y	Z
1	102.3050	100.5000	10.6350	**20**	101.3090	98.0100	11.2260	**38**	99.3650	106.5527	11.3700
2	102.3170	100.5000	11.2357	**21**	100.5373	97.8870	11.0300	**39**	99.3703	106.5530	10.9123
3	102.3183	100.4993	11.7117	**22**	100.5287	97.9023	10.4037	**40**	99.3720	106.5447	10.4960
5	102.2970	99.5660	12.1630	**23**	99.3993	97.8830	11.0303	**41**	100.1297	106.5313	10.5020
6	102.3007	99.5670	11.7093	**24**	99.3997	97.8970	10.3957	**42**	100.1290	106.5420	10.9113
7	102.2997	99.5690	11.2373	**27**	98.3837	99.7210	10.3363	**43**	100.1280	106.5440	11.3730
8	102.2847	99.5700	10.6323	**29**	98.4250	101.2580	11.2237	**44**	100.1280	106.5467	11.7313
10	102.2783	99.0330	10.9893	**30**	98.4257	101.2570	10.3360	**45**	100.8850	106.5357	11.7303
11	102.2750	99.0337	11.4220	**31**	98.4490	102.4000	10.3427	**46**	100.8870	106.5343	11.3723
12	102.2747	99.0320	11.7893	**32**	98.4540	102.4067	11.2243	**47**	100.8887	106.5330	11.0053
13	102.2290	98.3323	11.7913	**33**	98.7770	104.5030	12.0133	**63**	98.4730	103.0477	11.7360
15	102.2290	98.3307	10.9890	**34**	98.8087	104.5087	10.2850	**64**	98.4717	103.0463	11.4827
17	101.8990	98.0073	11.2190	**35**	98.8570	105.4680	10.2847	**66**	99.9650	98.9000	10.0060
18	101.8977	98.0030	12.0683	**36**	98.8260	105.4737	12.0177	**67**	101.3280	99.9200	10.0050
19	101.3050	98.0013	12.0683	**37**	99.3663	106.5557	11.7310	**70**	100.9510	104.4600	10.0020

Now that all the reductions have been completed we can compare the data from the two scanners. 42 Target's have been compared on the X,Y and Z values from both Scanners. 4 targets out of the 42 are outside the +-2mm tolerance. 38 targets are within -1 to 2mm , this is a very good result. Overall 54% of the total targets installed were used for the final scanner to scanner comparison Table 4.23. In the reductions section of this chapter targets that were not used have been explained.

Table 4.23 Faro Focus 3D X330 & P20 Comparisons

Leica P20 Scanner				**Faro Focus 3D X330**				**Diff X**	**Diff Y**	**Diff Z**
Target	X	Y	Z	**Target**	X	Y	Z	(mm)	(mm)	(mm)
1	102.3055	100.5000	10.6350	**1**	102.3050	100.5000	10.6350	0	0	0
2	102.3180	100.5000	11.2360	**2**	102.3170	100.5000	11.2357	1	0	0
3	102.3190	100.4990	11.7120	**3**	102.3183	100.4993	11.7117	1	0	0
4	102.3187	100.4993	12.1600	**4**						
5	102.2980	99.5663	12.1637	**5**	102.2970	99.5660	12.1630	1	0	1
6	102.3010	99.5680	11.7100	**6**	102.3007	99.5670	11.7093	0	1	1
7				**7**	102.2997	99.5690	11.2373			
8	102.2850	99.5693	10.6320	**8**	102.2847	99.5700	10.6323	0	-1	0
9	102.2673	99.0373	10.3120	**9**						
10				**10**	102.2783	99.0330	10.9893			
11	102.2753	99.0340	11.4223	**11**	102.2750	99.0337	11.4220	0	0	0
12	102.2750	99.0323	11.7897	**12**	102.2747	99.0320	11.7893	0	0	0
13	102.2290	98.3330	11.7920	**13**	102.2290	98.3323	11.7913	0	1	1
14				**14**						
15				**15**	102.2290	98.3307	10.9890			
16				**16**						
17	101.8990	98.0080	11.2197	**17**	101.8990	98.0073	11.2190	0	1	1
18	101.8990	98.0033	12.0690	**18**	101.8977	98.0030	12.0683	1	0	1
19	101.3063	98.0020	12.0707	**19**	101.3050	98.0013	12.0683	1	1	2
20	101.3090	98.0100	11.2287	**20**	101.3090	98.0100	11.2260	0	0	3
21	100.5377	97.8873	11.0320	**21**	100.5373	97.8870	11.0300	0	0	2
22	100.5290	97.9017	10.4060	**22**	100.5287	97.9023	10.4037	0	-1	2
23	99.3997	97.8827	11.0327	**23**	99.3993	97.8830	11.0303	0	0	2
24	99.4000	97.8963	10.3977	**24**	99.3997	97.8970	10.3957	0	-1	2
25				**25**						
26				**26**						
27	98.3840	99.7220	10.3390	**27**	98.3837	99.7210	10.3363	0	1	3
28	98.3837	99.7197	11.2270	**28**						
29	98.4260	101.2577	11.2260	**29**	98.4250	101.2580	11.2237	1	0	2
30	98.4250	101.2567	10.3380	**30**	98.4257	101.2570	10.3360	-1	0	2
31	98.4493	102.3997	10.3443	**31**	98.4490	102.4000	10.3427	0	0	2
32	98.4550	102.4060	11.2270	**32**	98.4540	102.4067	11.2243	1	-1	3
33	98.7773	104.5033	12.0143	**33**	98.7770	104.5030	12.0133	0	0	1
34	98.8080	104.5085	10.2860	**34**	98.8087	104.5087	10.2850	-1	0	1
35	98.8560	105.4670	10.2845	**35**	98.8570	105.4680	10.2847	-1	-1	0
36	98.8260	105.4733	12.0180	**36**	98.8260	105.4737	12.0177	0	0	0
37	99.3660	106.5560	11.7313	**37**	99.3663	106.5557	11.7310	0	0	0
38	99.3653	106.5530	11.3700	**38**	99.3650	106.5527	11.3700	0	0	0
39	99.3710	106.5530	10.9117	**39**	99.3703	106.5530	10.9123	1	0	-1
40	99.3720	106.5450	10.4957	**40**	99.3720	106.5447	10.4960	0	0	0
41	100.1300	106.5320	10.5010	**41**	100.1297	106.5313	10.5020	0	1	-1
42	100.1293	106.5420	10.9113	**42**	100.1290	106.5420	10.9113	0	0	0
43	100.1280	106.5440	11.3747	**43**	100.1280	106.5440	11.3730	0	0	2
44	100.1290	106.5470	11.7310	**44**	100.1280	106.5467	11.7313	1	0	0
45	100.8860	106.5363	11.7293	**45**	100.8850	106.5357	11.7303	1	1	-1
46	100.8873	106.5343	11.3710	**46**	100.8870	106.5343	11.3723	0	0	-1
47	100.8893	106.5330	11.0040	**47**	100.8887	106.5330	11.0053	1	0	-1
48	100.8957	106.5183	10.4957	**48**						
49				**49**						
50				**50**						
51				**51**						
52				**52**						
53	102.4610	105.9800	11.5517	**53**						
54	102.4505	105.9825	10.9080	**54**						
55	102.4293	105.0077	10.9080	**55**						
56	102.4427	105.0117	11.5530	**56**						
57	98.3805	99.0575	11.7545	**57**						
58	98.3780	99.0570	11.5255	**58**						
59	98.4007	100.3877	11.5260	**59**						
60	98.4037	100.3887	11.7550	**60**						
61				**61**						
62	98.4377	101.7197	11.4853	**62**						
63	98.4733	103.0477	11.7380	**63**	98.4730	103.0477	11.7360	0	0	2
64	98.4713	103.0457	11.4850	**64**	98.4717	103.0463	11.4827	0	-1	2
65	101.2797	98.9493	10.0090	**65**						
66	99.9650	98.8995	10.0080	**66**	99.9650	98.9000	10.0060	0	-1	2
67	101.3270	99.9175	10.0080	**67**	101.3280	99.9200	10.0050	-1	-2	3
68	100.0680	105.6140	10.0035	**66**						
69	101.0185	105.6070	10.0070	**67**						
70	100.9520	104.4600	10.0030	**70**	100.9510	104.4600	10.0020	1	0	1

4.4 Scan and Track Survey Comparison

One of the objectives for this research was if the TLS conformed with Sydney Trains Specifications, a section of rail track in the rail corridor will be scanned from two positions. Due to safety constraints only one position was used. Figure 4.8 (a) shows the registered point cloud overlayed with independently measured survey points using a Leica TS15. The same Survey control was used for this comparison as described in detail in Chapter 3. Point 810 was one of the survey radiation on the catenary overhead wire attached to a mast. The figure clearly shows this point has fallen on the invert of the wire as it was radiated. Point 925 and 926 were survey points of the centre of two bolts exactly as they have been scanned. These were very good results .

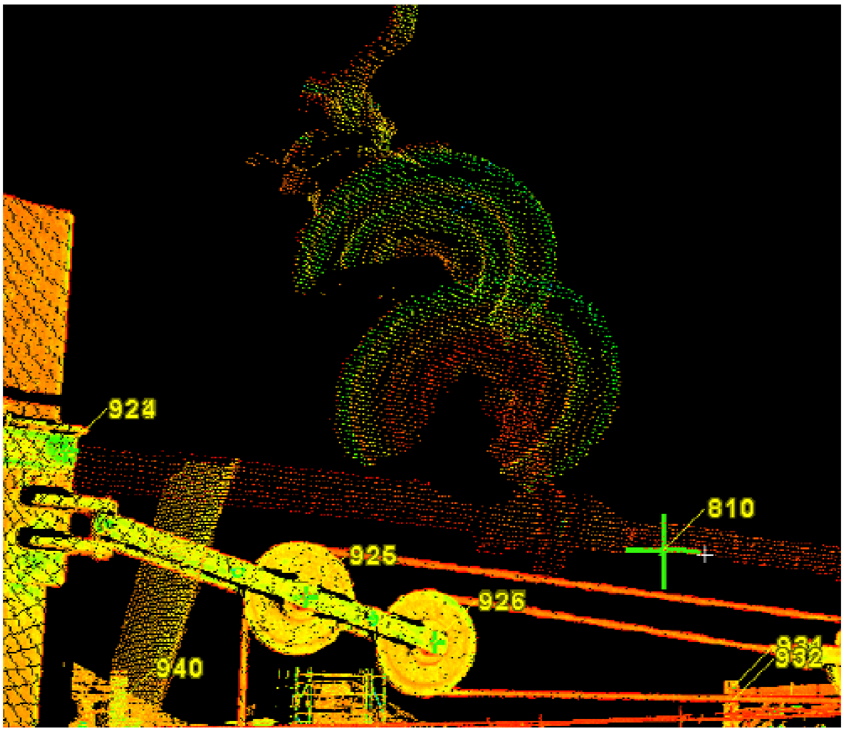


Figure 4.8 Survey Points overlayed onto point cloud capture in Cyclone 9.0.

The scan time for this scene capture was 6 minutes and survey time was 45 minutes. A significant difference. Accuracy is certainly not an issue but the coordination of safety personnel and survey crew combined with gaining access to the danger zone had a tremendous impact on the time taken to complete the task. Scanning allows measurements in the form of a scene capture remotely from a safe place by a single individual. This is assuming scan targets have been permanently installed within rail corridor for resection purposes. Current survey methods require most times the direct measurement to a circular prism to define a feature in 3D.

The Faro focus 3D X330 scanner was also used for this scene capture. The scanner was setup on a carbon fibre camera tripod and during the scan there was a change in weather conditions in the wind. These two unfortunate factors had an impact to the final point cloud. The point cloud was warped and the comparison to the survey points done with the Leica P20 was not able to be completed with the Faro.

4.5 Discussion

All the ground work done to construct solid, strong targets, assisted in the accuracy of the results. In previous research the improvement of a scanner from before and after calibration was expressed as a percentage of improvement. This research using current model scanners has shown results that are so good, the before and after accuracy improvement method might no longer be required based on the results from this work on certain scanners.

Disappointing outcomes with reflectorless mode on the Survey Total Stations. This functionality is not pin point accuracy, as the size of the laser dot varies in distortion due to incident angles it effects the accuracy of the measurement. It is noted that manufactures recommend measurements are not made when the incident angles are tight but in real word Survey situations you need to make measurements everywhere. You cannot be restricted by instruments that do not maintain accuracy in difficult scenarios.

During the signalisation process of Targets in Site A, from certain ground station positions, pointing to the centre of targets and the SSP's was difficult - the vertical sighting angle was very steep to sight through the telescope. In consultation with CR Kennedy during the second calibration facility target installation, the laser of the TS15 STS was tested to confirm the pin point cross hairs when sighting to a target coincide with the laser dot being located in the centre of the target as well. If it was off centre the instrument will be adjusted in the CR Kennedy service department. From the disturbed shape of the laser dot on some of the photographs of the targets, the laser will need to be tested over 50m. The laser pointer and the reflectorless laser is one and the same and it was correct no adjustment was required.

The comparison of the Faro Focus 3D X330 and the P20 was excellent. 90% of the targets used to compare scanner to scanner were well within the tolerance range of +-2mm. It is interesting comparing the Leica P20 to the Signalised targets the two targets that did not agree were Faro scanner targets. With the Faro there was a great amount of targets that did not agree with the Signalised targets and the majority were Leica targets.

The results show that the STS data compared to the Scanner data are within +-2mm in 3D positional coordinates. This result shows that the Terrestrial Laser Scanners Leica P20 and Faro Focus 3D X330 are as accurate as the Survey Total Stations therefore conforms with Sydney Trains Specifications and can be used in the rail corridor. Of course scans taken in the rail corridor and a point cloud in the deliverable it will need to submit an accuracy verification conformance. A comparisons of signalised versus scanned targets installed in an indoor room, to show the scanner being used for the measurements conforms with Specifications this research has shown could be acceptable.

Chapter Five - Conclusion and Recommendation

5.1 Conclusion

In conclusion the aims of the project were achieved. Documented working accuracies have been provided for the Leica P20 and faro Focus 3D X330 and shows conformance with Sydney Trains Specifications. The Track Control marks (TCM's) have been scanned accurately indicating no interference by the installed SSP's in the centre of the scanner targets (both Leica and Faro) during the centroid extraction process. The scan time and mainstream survey methods to capture measurements of a section of rail track has also been documented.

The objectives of the research work have also been achieved:

- A literature review on TLS and current application within a Railway environment were completed and documented
- A calibration indoor target network was designed and established at site A and then Site B
- Various custom and manufactured targets were constructed, modified and installed for scanning
- An indoor self calibration of two scanners was completed using all the installed targets. The Leica P20 and the Faro Focus 3D X330
- All calibration room indoor targets were signalised by two Survey Total Stations. The Leica TS15 and TS30 prior to scanning.
- A section of track was scanned by both scanners and a comparison of the point clouds and surveyed features have been illustrated.
- One of the findings in the research was that the manufactured scan Targets can have survey marks, in this case SSP's installed in the centre. The centroid of the target can still be automatically extracted even if a steel pin is installed in the centre of the algorithmic pattern. This was a great discovery which impacts the method of installation of Sydney Trains Survey Control Marks and Track control Marks in the future so they can be used for scanning.
- This research also verified that different brand scanners can recognise the checker scan targets of other manufactures and extract there centres.
- All other findings have been documented.

The ppm accuracy has not been checked due to the short lengths of the baselines, in the indoor calibration room. The lines being less than 10 meters. Sydney Trains specifications state the acceptable angular accuracy is < 1.5". The TLS measures the 3D spatial position and exported the raw data as coordinates only so the angular accuracy for this work was not determined. This was the case for both scanners used in this work. The results do indicate there is no zero error in the scanner instruments.

5.2 Recommendation

On completed this research the following recommendations can be made:

- TLS must be aligned with a formal calibration test so it can be used on Survey Projects to produce and maintain accurate deliverables. In NSW, it is recommended that the Land Property Information (LPI) further investigate the design, construction and maintenance of a self calibration facility for Terrestrial Laser Scanners.
- Development of documented calibration standard procedures working together with the LPI is also research work that can further investigated.
- It would be interesting to have used another brand Survey Total Station for the reflectorless signalisation of the Targets. Topcon the manufacture of Survey Total Stations, claim that the laser beam in there instrument is a fixed diameter, pin point dot. The size of the laser dot does not change depending on the distance being measured. It is recommended that this should be tested.
- An investigation of the design of rail specific scan targets and permanent installation within the rail corridor is recommended. It will require measuring these new targets with a STS to establish control values first.
- The construct of new targets integrating checker board targets with a glass prism to make it easier to signalise targets in a calibration room would certainly speed the process of signalisation.
- During the construction phase of this project colour tone cards were fitted to Leica GPH1 prism holder. This concept could be tested on an EDM baseline as a check on STS Reflectorless measurements.
- Waveform Digitising (WFD) measuring technology could be investigated. The testing and analysis of WFD was outside the scope of this research but needs to researched especially now that manufactures are introducing it in the new Survey Total Station and scanners.

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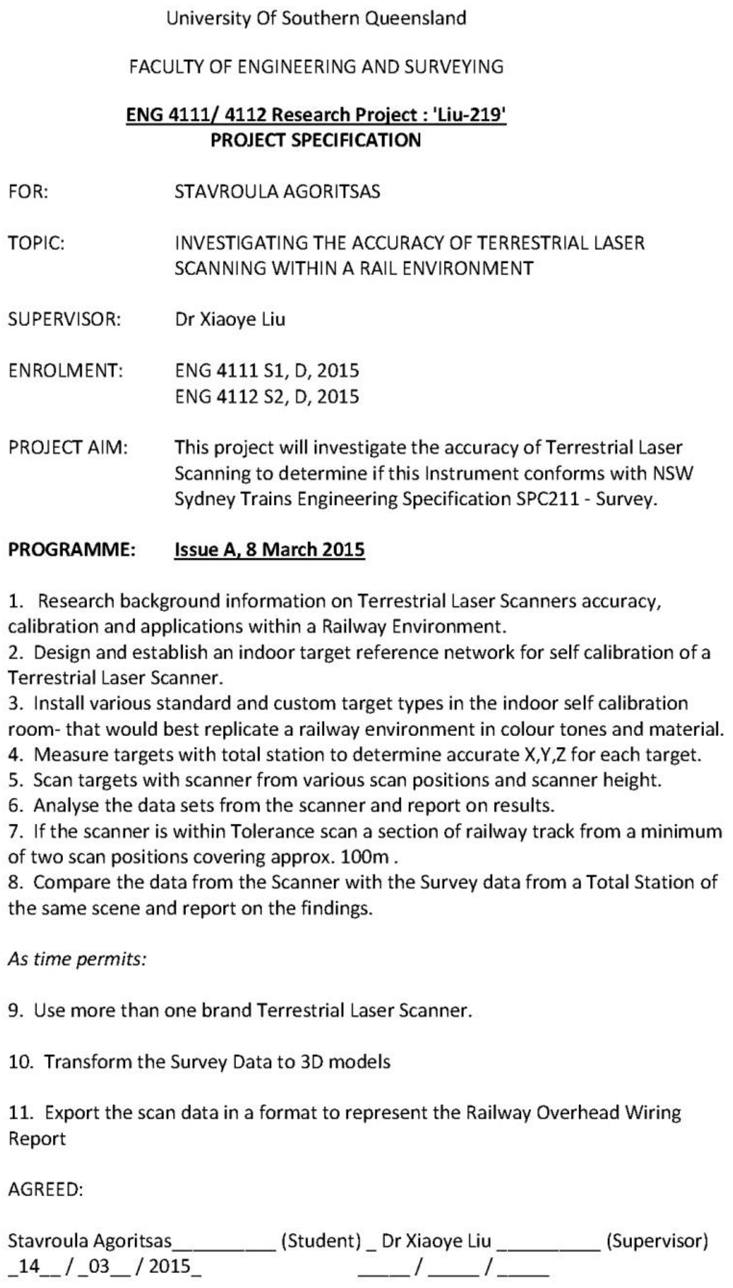
Appendix A. Project Specification



University Of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/ 4112 Research Project : 'Liu-219'
PROJECT SPECIFICATION

FOR:	STAVROULA AGORITSAS
TOPIC:	INVESTIGATING THE ACCURACY OF TERRESTRIAL LASER SCANNING WITHIN A RAIL ENVIRONMENT
SUPERVISOR:	Dr Xiaoye Liu
ENROLMENT:	ENG 4111 S1, D, 2015 ENG 4112 S2, D, 2015
PROJECT AIM:	This project will investigate the accuracy of Terrestrial Laser Scanning to determine if this Instrument conforms with NSW Sydney Trains Engineering Specification SPC211 - Survey.
PROGRAMME:	**Issue A, 8 March 2015**

1. Research background information on Terrestrial Laser Scanners accuracy, calibration and applications within a Railway Environment.
2. Design and establish an indoor target reference network for self calibration of a Terrestrial Laser Scanner.
3. Install various standard and custom target types in the indoor self calibration room- that would best replicate a railway environment in colour tones and material.
4. Measure targets with total station to determine accurate X,Y,Z for each target.
5. Scan targets with scanner from various scan positions and scanner height.
6. Analyse the data sets from the scanner and report on results.
7. If the scanner is within Tolerance scan a section of railway track from a minimum of two scan positions covering approx. 100m .
8. Compare the data from the Scanner with the Survey data from a Total Station of the same scene and report on the findings.

As time permits:

9. Use more than one brand Terrestrial Laser Scanner.

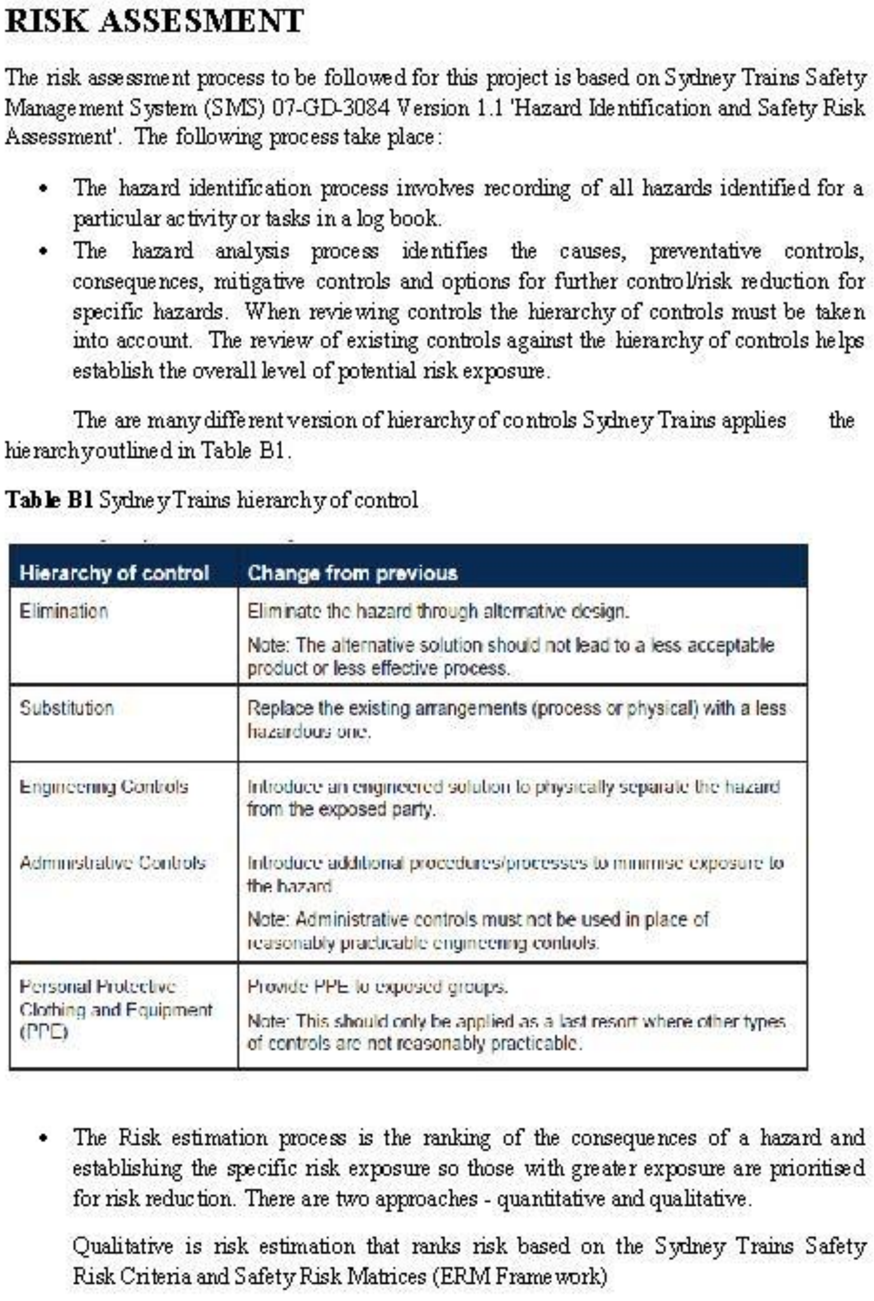
10. Transform the Survey Data to 3D models

11. Export the scan data in a format to represent the Railway Overhead Wiring Report

AGREED:

Stavroula Agoritsas__________ (Student) _ Dr Xiaoye Liu __________ (Supervisor)
_14__ / _03__ / 2015_ _____ / _____ / _____

Appendix B. Risk Assessment and Safety



RISK ASSESMENT

The risk assessment process to be followed for this project is based on Sydney Trains Safety Management System (SMS) 07-GD-3084 Version 1.1 'Hazard Identification and Safety Risk Assessment'. The following process take place:

- The hazard identification process involves recording of all hazards identified for a particular activity or tasks in a log book.
- The hazard analysis process identifies the causes, preventative controls, consequences, mitigative controls and options for further control/risk reduction for specific hazards. When reviewing controls the hierarchy of controls must be taken into account. The review of existing controls against the hierarchy of controls helps establish the overall level of potential risk exposure.

The are many different version of hierarchy of controls Sydney Trains applies the hierarchy outlined in Table B1.

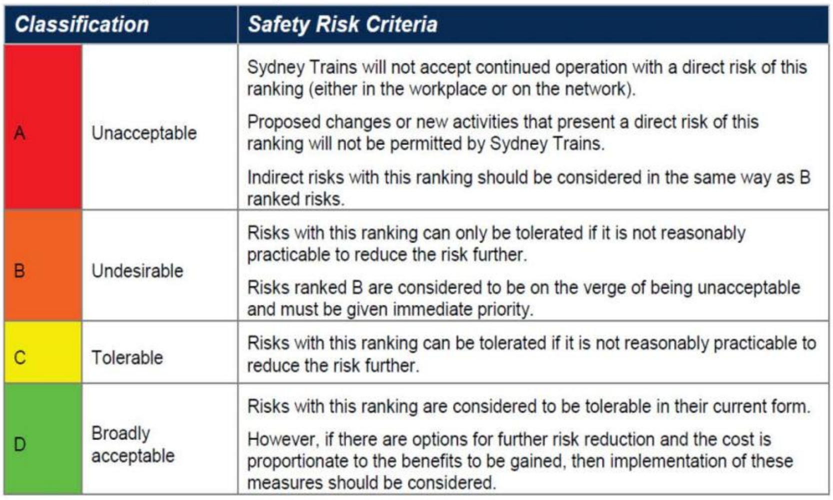
Table B1 Sydney Trains hierarchy of control

Hierarchy of control	Change from previous
Elimination	Eliminate the hazard through alternative design. Note: The alternative solution should not lead to a less acceptable product or less effective process.
Substitution	Replace the existing arrangements (process or physical) with a less hazardous one.
Engineering Controls	Introduce an engineered solution to physically separate the hazard from the exposed party.
Administrative Controls	Introduce additional procedures/processes to minimise exposure to the hazard. Note: Administrative controls must not be used in place of reasonably practicable engineering controls.
Personal Protective Clothing and Equipment (PPE)	Provide PPE to exposed groups. Note: This should only be applied as a last resort where other types of controls are not reasonably practicable.

- The Risk estimation process is the ranking of the consequences of a hazard and establishing the specific risk exposure so those with greater exposure are prioritised for risk reduction. There are two approaches - quantitative and qualitative.

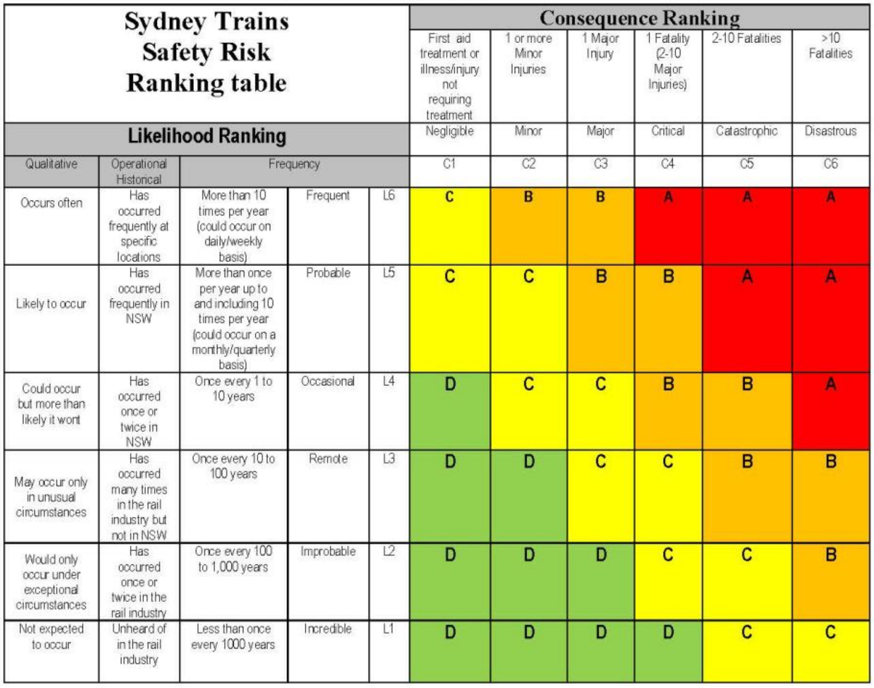
  Qualitative is risk estimation that ranks risk based on the Sydney Trains Safety Risk Criteria and Safety Risk Matrices (ERM Framework)

Table B2 Sydney Trains Safety Risk criteria



Classification		Safety Risk Criteria
A	Unacceptable	Sydney Trains will not accept continued operation with a direct risk of this ranking (either in the workplace or on the network). Proposed changes or new activities that present a direct risk of this ranking will not be permitted by Sydney Trains. Indirect risks with this ranking should be considered in the same way as B ranked risks.
B	Undesirable	Risks with this ranking can only be tolerated if it is not reasonably practicable to reduce the risk further. Risks ranked B are considered to be on the verge of being unacceptable and must be given immediate priority.
C	Tolerable	Risks with this ranking can be tolerated if it is not reasonably practicable to reduce the risk further.
D	Broadly acceptable	Risks with this ranking are considered to be tolerable in their current form. However, if there are options for further risk reduction and the cost is proportionate to the benefits to be gained, then implementation of these measures should be considered.

Table B3 Sydney Trains Safety Risk Ranking Table.



Sydney Trains Safety Risk Ranking table					Consequence Ranking					
					First aid treatment or illness/injury not requiring treatment	1 or more Minor Injuries	1 Major Injury	1 Fatality (2-10 Major Injuries)	2-10 Fatalities	>10 Fatalities
Likelihood Ranking					Negligible	Minor	Major	Critical	Catastrophic	Disastrous
Qualitative	Operational Historical	Frequency			C1	C2	C3	C4	C5	C6
Occurs often	Has occurred frequently at specific locations	More than 10 times per year (could occur on daily/weekly basis)	Frequent	L6	C	B	B	A	A	A
Likely to occur	Has occurred frequently in NSW	More than once per year up to and including 10 times per year (could occur on a monthly/quarterly basis)	Probable	L5	C	C	B	B	A	A
Could occur but more than likely it wont	Has occurred once or twice in NSW	Once every 1 to 10 years	Occasional	L4	D	C	C	B	B	A
May occur only in unusual circumstances	Has occurred many times in the rail industry but not in NSW	Once every 10 to 100 years	Remote	L3	D	D	C	C	B	B
Would only occur under exceptional circumstances	Has occurred once or twice in the rail industry	Once every 100 to 1,000 years	Improbable	L2	D	D	D	C	C	B
Not expected to occur	Unheard of in the rail industry	Less than once every 1000 years	Incredible	L1	D	D	D	D	C	C

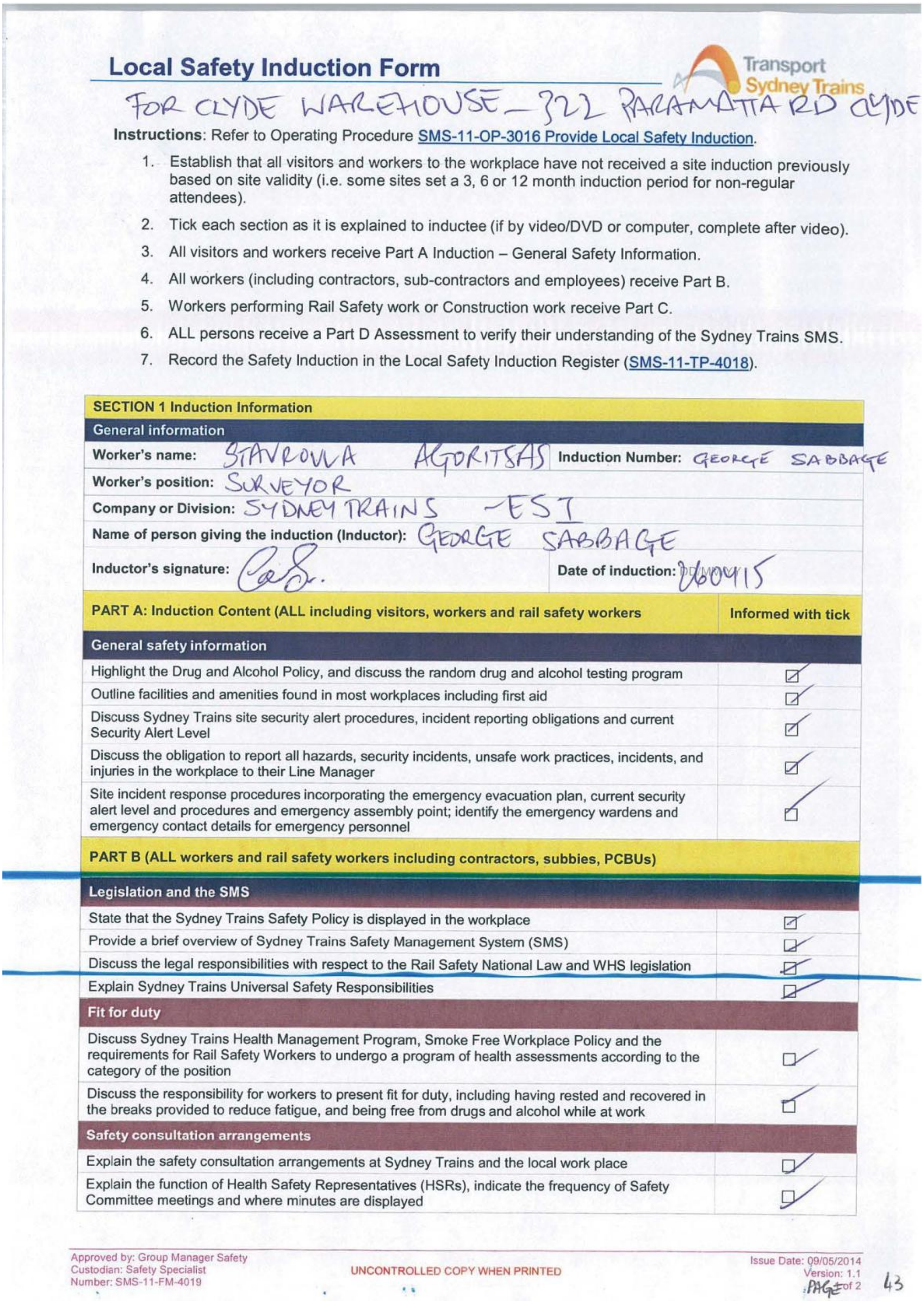
- Reporting is the final process of the risk management assessment. All risk assessments must be formally documented.

For the work undertaken for this project the completion of a risk assessment is not required because there is a current Safe Work method Statement (SWMS) SMS-06-SW-1110 to undertake this Work which will be used to sign on to satisfy the requirements of having a risk management plan in place prior to commencing project Work.

For th survey work undertaken indoors a site inductions was completed and briefed by the warehouse manager and together with our SWMS we satisfied the Sydney Trains workplace risk management plan.

For the project Work conducted in the Rail corridor the following safety documents were also completed :

- SMS-06-FM-0163 pre work briefing
- NRF 015A worksite protection plan
- NRF 015B Worksite protection plan for lookout working



Local Safety Induction Form

Transport
Sydney Trains

FOR CLYDE WAREHOUSE – 322 PARAMATTA RD CLYDE

Instructions: Refer to Operating Procedure SMS-11-OP-3016 Provide Local Safety Induction.

1. Establish that all visitors and workers to the workplace have not received a site induction previously based on site validity (i.e. some sites set a 3, 6 or 12 month induction period for non-regular attendees).
2. Tick each section as it is explained to inductee (if by video/DVD or computer, complete after video).
3. All visitors and workers receive Part A Induction – General Safety Information.
4. All workers (including contractors, sub-contractors and employees) receive Part B.
5. Workers performing Rail Safety work or Construction work receive Part C.
6. ALL persons receive a Part D Assessment to verify their understanding of the Sydney Trains SMS.
7. Record the Safety Induction in the Local Safety Induction Register (SMS-11-TP-4018).

SECTION 1 Induction Information	
General information	
Worker's name: STAVROULA AGORITSAS	**Induction Number:** GEORGE SABBAGE
Worker's position: SURVEYOR	
Company or Division: SYDNEY TRAINS – EST	
Name of person giving the induction (Inductor): GEORGE SABBAGE	
Inductor's signature:	**Date of induction:** 260415

PART A: Induction Content (ALL including visitors, workers and rail safety workers	**Informed with tick**
General safety information	
Highlight the Drug and Alcohol Policy, and discuss the random drug and alcohol testing program	☑
Outline facilities and amenities found in most workplaces including first aid	☑
Discuss Sydney Trains site security alert procedures, incident reporting obligations and current Security Alert Level	☑
Discuss the obligation to report all hazards, security incidents, unsafe work practices, incidents, and injuries in the workplace to their Line Manager	☑
Site incident response procedures incorporating the emergency evacuation plan, current security alert level and procedures and emergency assembly point; identify the emergency wardens and emergency contact details for emergency personnel	☑
PART B (ALL workers and rail safety workers including contractors, subbies, PCBUs)	
Legislation and the SMS	
State that the Sydney Trains Safety Policy is displayed in the workplace	☑
Provide a brief overview of Sydney Trains Safety Management System (SMS)	☑
Discuss the legal responsibilities with respect to the Rail Safety National Law and WHS legislation	☑
Explain Sydney Trains Universal Safety Responsibilities	☑
Fit for duty	
Discuss Sydney Trains Health Management Program, Smoke Free Workplace Policy and the requirements for Rail Safety Workers to undergo a program of health assessments according to the category of the position	☑
Discuss the responsibility for workers to present fit for duty, including having rested and recovered in the breaks provided to reduce fatigue, and being free from drugs and alcohol while at work	☑
Safety consultation arrangements	
Explain the safety consultation arrangements at Sydney Trains and the local work place	☑
Explain the function of Health Safety Representatives (HSRs), indicate the frequency of Safety Committee meetings and where minutes are displayed	☑

Approved by: Group Manager Safety
Custodian: Safety Specialist
Number: SMS-11-FM-4019

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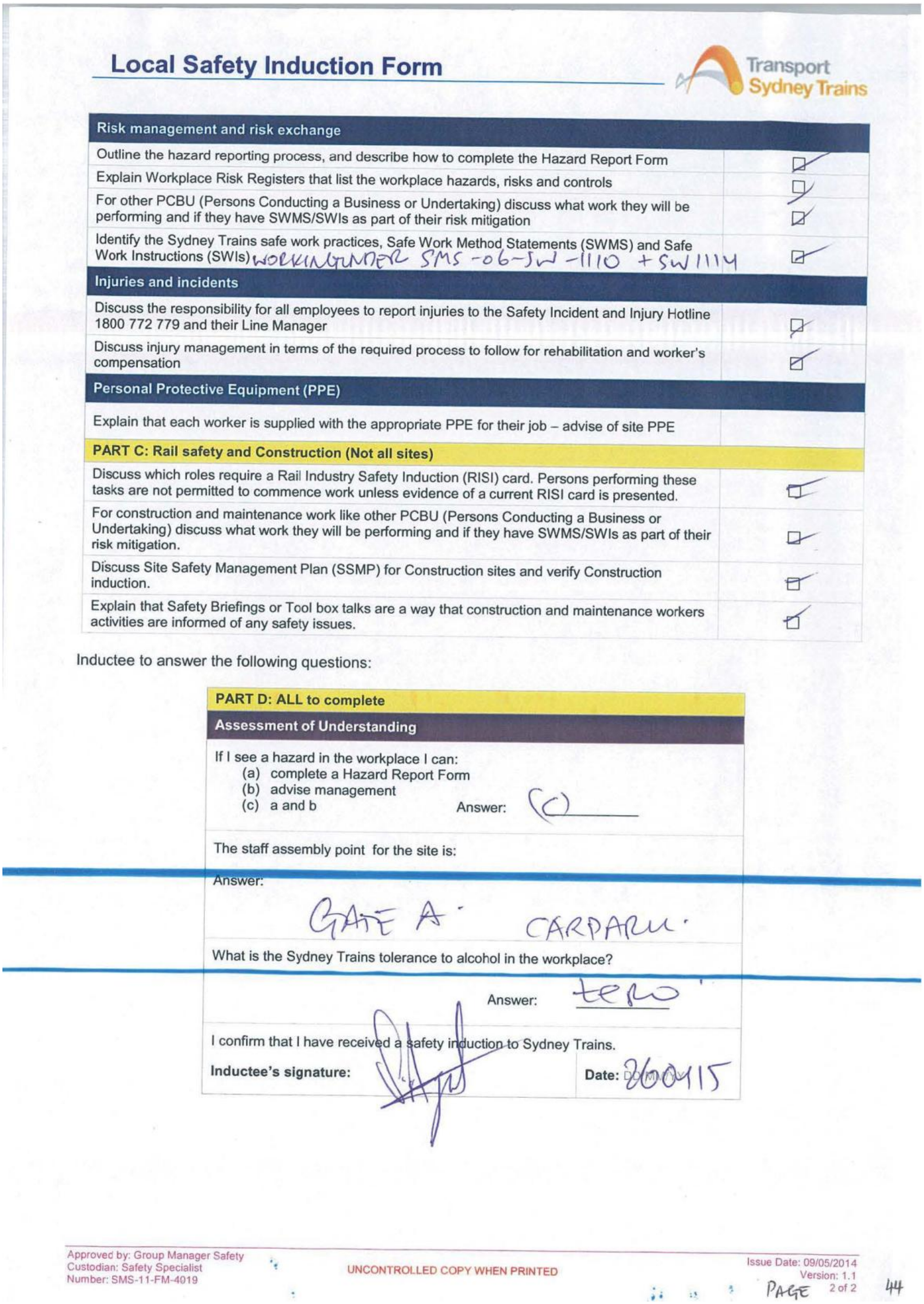

Local Safety Induction Form

Transport
Sydney Trains

Risk management and risk exchange	
Outline the hazard reporting process, and describe how to complete the Hazard Report Form	☑
Explain Workplace Risk Registers that list the workplace hazards, risks and controls	☑
For other PCBU (Persons Conducting a Business or Undertaking) discuss what work they will be performing and if they have SWMS/SWIs as part of their risk mitigation	☑
Identify the Sydney Trains safe work practices, Safe Work Method Statements (SWMS) and Safe Work Instructions (SWIs) WORKINGUNDER SMS-06-SW-1110 + SW 1114	☑
Injuries and incidents	
Discuss the responsibility for all employees to report injuries to the Safety Incident and Injury Hotline 1800 772 779 and their Line Manager	☑
Discuss injury management in terms of the required process to follow for rehabilitation and worker's compensation	☑
Personal Protective Equipment (PPE)	
Explain that each worker is supplied with the appropriate PPE for their job – advise of site PPE	
PART C: Rail safety and Construction (Not all sites)	
Discuss which roles require a Rail Industry Safety Induction (RISI) card. Persons performing these tasks are not permitted to commence work unless evidence of a current RISI card is presented.	☑
For construction and maintenance work like other PCBU (Persons Conducting a Business or Undertaking) discuss what work they will be performing and if they have SWMS/SWIs as part of their risk mitigation.	☑
Discuss Site Safety Management Plan (SSMP) for Construction sites and verify Construction induction.	☑
Explain that Safety Briefings or Tool box talks are a way that construction and maintenance workers activities are informed of any safety issues.	☑

Inductee to answer the following questions:

PART D: ALL to complete

Assessment of Understanding

If I see a hazard in the workplace I can:
(a) complete a Hazard Report Form
(b) advise management
(c) a and b
Answer: (C)

The staff assembly point for the site is:

Answer:
GATE A. CARPARK.

What is the Sydney Trains tolerance to alcohol in the workplace?

Answer: zero

I confirm that I have received a safety induction to Sydney Trains.

Inductee's signature: **Date:** DD/MM/YY 26 04 15

Approved by: Group Manager Safety
Custodian: Safety Specialist
Number: SMS-11-FM-4019

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Transport
Sydney Trains

Pre-work Briefing – Worksite protection/work method

Work location: CLYDE WAREHOUSE

Briefing date: ~~26-4-15~~ SA 17/3/15

Scope of work: TARGET INSTALATIONS

Site Supervisor: S.AGORITSAS

Phone: 0458345327

Work on track method (LPA, TOA, TWA, ASB, Lookout Working)
Refer to Worksite Protection Plan for details: NO WORK ON TRACK SA 17/3/15

Protection Officer: S.AGORITSAS.

Phone: 0458345327.

Emergency assembly point: GATE A AT CARPARK (AS INSTRUCTED DURING INDUCTION)

Briefer: S.AGORITSAS.

Briefer's signature:

First aid kit location: SYDNEY TRAINS VEHICLE. (WITH WORKERS)

First Aider: S.AGORITSAS

SWMS/SWI Ref #:

Hazards (eg. Site specific hazards identified, including physical environment, human errors, plant and equipment)	**Controls** (to be implemented to eliminate or reduce the risk to the lowest practicable level)	**Person responsible for Control**
SLIPS TRIPS FALLS	PPE. WATCHING YOUR FOOTING.	ALL
WORKING AT HEIGHTS	BRIEFED ON SMS06-OP3036. THREE POINT CONTACT ON LADDER AT ALL TIMES	ALL
MOVING FORKLIFTS	AREA ISOLATED, SIGNS PLACES.	ALL
HEAT, EXHAUSTION.	TAKE REGULAR BRAKES, DRINK WATER.	ALL.
LADDER SLIP	PERSON ALLOCATED TO HOLD	ALL
	AND WEDGE LADDER AT ALL TIMES	ALL.
	BRIEFED ON SMS-06-SW-0264.	

NRF 014 V 3.0
1 of 2

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NSW | Transport RailCorp

Safe Work Instruction

Portable Ladders, Stepladders and Step Platforms

Issue date: 19/10/11

Review date: 18/10/14

Document no.
SMS-06-SW-0264

Work description
Selection, use and care of portable ladders, stepladders and step platforms.

Working with ladders near electrical equipment.

A ladder is used for gaining access to areas above or below the ground, or other levels not provided with permanent access. A step platform is a very stable work surface for working at height.

Scope
This SWI does not apply to fixed ladders or platforms. Refer to AS 1657.

Review date
18/04/14

References

- OHS Reg 2001 Clause 39, 56-61
- AS/NZS 1892.5:2000 Portable ladders – Selection, safe use and care
- AS 4142.2: 1993 Fibre Ropes
- WorkCover Portable Ladders Safety Guide No: 4503, 1999
- WorkCover Position Paper, Working Off Stepladders, 2003
- SMS-16-SR-0057 Workplace Health and Safety Inspection, Testing and Calibration
- SMS-13-PR-0294 Managing Safety in Procurement - Goods
- SMS-06-PR-0240 Working at Heights
- SMS-06-GD-0268 Working Around Electrical Equipment
- SMS-06-SW-0260 Physical Restraint Systems (Pole Straps)
- SMS-06-SW-0267 Working in Accordance with an Electrical Permit

Responsible supervisor *Insert name in BLOCK letters*	**PPE and precautions**	**Competencies or qualifications**	**Licences or permits required**
	• High vis vest where required • Non-slip footwear	See below	N/A

Tools and equipment required
If the worker goes to a height of greater than 1.8 metres, provide:

- an appropriate harness and safety lines
- pole straps, if needed.

IF CONTROL MEASURES ARE NOT SUITABLE AND MAJOR CHANGES ARE NEEDED, CONDUCT A RISK ASSESSMENT AND DEVELOP NEW CONTROLS ACCORDING TO SMS-06-PR-1479 OHS RISK MANAGEMENT.

⚠ ***Warning***
In the past five years (to 2006), at least 83 people in Australia have died after falling from a ladder and thousands more have been seriously injured. Avoid performing work from a ladder. Ladders are intended for access and egress only.

Selecting portable ladders

As a general rule, use a ladder as a means of access and not as a place of work.

Ladders are to be industrial rated to 120 Kg. Do not use domestic ladders.

The Line Manager is to select ladders that are:

- able to extend at least 1m higher than the highest level that needs to be accessed
- capable of supporting the greatest load to be imposed
- no longer than the lengths specified below.

Maximum lengths

Metal ladders and reinforced plastic ladders	**Timber ladders**
• 6.1m for an industrial stepladder • 9m for a single industrial ladder • 15m for an industrial extension ladder	• 5.5m platform stepladder • 5.5m industrial

⚠ ***Warning***
Do not use metal ladders for electrical work.

Stepladders

Stepladders are to be used in the fully open position.

A person using a stepladder can carry out work that requires the simultaneous release of both hands from the stepladder only under the following circumstances:

- the working height is limited to accessing the ceiling or soffit of the floor above which the stepladder is positioned, or to 1.8 metres elsewhere
- the person and the stepladder are to remain stable throughout the period of work
- the person is to have the use of both hands to grip the stepladder when ascending and descending the ladder
- except for stepladders incorporating an appropriately guarded work platform, the person does not work above the third step from the top of the stepladder
- the nature of the work allows the person to lean forward towards the stepladder
- where the work involves hand tools:
  - the tools are used as intended in their normal operating position
  - tool use does not negate guarding or other safety features on the tools
  - all tools are supported by the person undertaking the task (e.g. in a tool belt or tool bag) and are not supported from the stepladder, unless designed for the purpose
  - the tools, and the manner in which they are used, do not cause the centre of gravity of the person operating them to be shifted from the stable position of leaning towards the stepladder
  - the tools are relatively lightweight
- the nature of the work and the position of the stepladder, does not require the person to overstretch
- the work does not cause fatigue – it is of short-term duration and conducted in an ergonomic manner.

Where the above cannot be complied with do not use a stepladder – use a more suitable temporary work platform.

Step platforms

A commercially available step platform is a safer alternative to a stepladder – especially where the task involves extended periods working at height or with restricted vision (such as welding or other hot work).

A step platform is extremely stable and provides a much larger work surface than a stepladder.

If possible, procure a collapsible and height adjustable step platform. The height of the platform is to be compatible with the location of items of work. (See Figure 1)

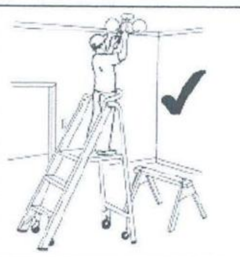


Figure 1 **Example of a step platform in use**

Identifying electrical hazards

Do not use metal ladders or wire-reinforced ladders to work:

- on or near low voltage electrical conductors
- within 6 m of live 1500 V overhead power supply or high voltage equipment
- if there are live electrical conductors nearby, consider the possibility of the conductor moving (e.g. due to wind), or the ladder moving (e.g. lean or sway) so that safe distances are maintained
- work near RailCorp electrical equipment can need an electrical work permit as described in Working Around Electrical Equipment guide
- work near non-RailCorp electrical conductors is to be authorised by their owner (e.g. Energy Australia, Integral Energy)

For more information, see the "Working Near Electrical Equipment" section on page 6 of this SWI.

Identifying other hazards

If working outdoors do not use ladders in very windy or wet conditions.

Inspect ladders before use and do not use ladders with faults such as damaged stiles, and missing or loose rungs.

Do not use a stepladder near the edge of an open floor, penetration, or on scaffolding to gain extra height.

Avoid setting up a ladder in a passageway, doorway, driveway or other place where a person, vehicle or crane-lifted load might hit it. (If the use of a ladder in a doorway is unavoidable, erect a barrier or keep the door locked.)

If a ladder is erected in a public area and may cause interference or give access to a hazardous location, do not leave it unattended. In the latter case, it may be disabled by securing a plank that covers the full width of the rungs onto the lower half of the ladder.

If a ladder can be left unattended and is remote from the work site, attach a sign reading "Warning - Do Not Remove – Workers Aloft" to the ladder.

Do not carry material and tools by hand when climbing the ladder. Material and tools which cannot be safely secured on the worker's belt are to be independently transferred or hoisted to the work location.

Avoid working directly over other people.

Do not allow anyone else to be on the ladder at the same time as you.

Always wear slip resistant footwear.

Make sure that the weight of person plus tools never exceeds 120 kg.

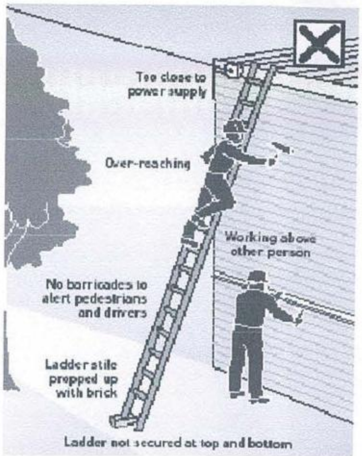


Figure 2 Example of dangerous ladder use

Setting up ladders

Heavy ladders (weighing over 20 kg) are to be handled by at least 2 workers.

Set up ladders so that:

- their slope is between 70° and 80°. (1 m horizontally for every 4m vertically is ideal)
- they extend at least 1m past the highest point that needs to be accessed
- their base and top are firmly secured by fixing or tying, or by another worker holding the base or top
- ties at the base or top of a ladder are attached to the stiles of the ladder, not the rungs
- if necessary, road and pedestrian traffic controls are in place, doors are locked etc.
- rungs are clean before the ladder is used.

There is to be adequate, stable, non-slippery and level support for the base of a ladder. If the ground is soft or uneven, wide planks can be used as a base.

The base of a ladder is not to be in a pedestrian or road traffic area, or next to a door or gate, unless there are adequate controls in place.

The tops of single and extension ladders are to be supported by a structure that is strong enough to bear the loads.

When adjusting the height of an extension ladder people are:

- not to be positioned on the ladder
- not to reach through the ladder
- to be careful to avoid injury from sliding guides and other components.

Before climbing an extension ladder after the height has been adjusted, the user is to look to make sure that the pawls are properly engaged.

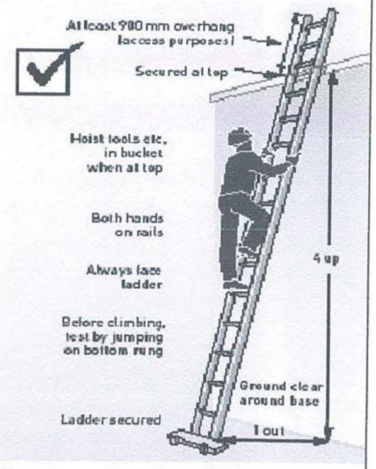


Figure 3 **Example of safe ladder use**

Securing ladders	**At the base**	When erected against a pole or structure, ladders are to be secured at the base before any person ascends them. The base rope is to be secured to the pole or structure and the tail of the base rope tied off to the other stile. A suitable warning device, such as a flag, is to be attached to the rope between the ladder and the pole or structure.
		If a ladder cannot be secured with the base rope, a person is to steady the base of the ladder to prevent it from slipping. It is not necessary to secure the base of a ladder less than 3m long.
	At the upper support	A ladder is to be secured to the upper support with the head rope and the tail of the head rope tied off to the other stile. This is to be done before work from the ladder commences or before people move from the ladder to the pole or the structure. While the ladder is being secured a person is to steady the base of the ladder to prevent it from slipping.
		When a ladder is secured at the upper support it is no longer necessary for a person to steady the ladder base.
		If a ladder cannot be secured to the upper support, a person is to continue to steady the base of the ladder to prevent it from slipping. In these cicumstances, the base is to be also secured with a rope if practicable.
		A person steadying a ladder is to firmly grasp the stiles with both hands to prevent any movement or overturn of the ladder. If a ladder is less than 3m long, it is not necessary to secure the top.

Securing ladders cont

Ladder lashing

To provide stability, an option is ladder lashing. (Figure 4)

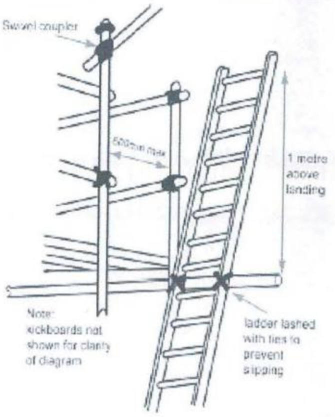


Figure 4 **Example of ladder lashing**

Using ladders

The decision to use of ladders is not to be governed by time and cost factors.

Use a ladder for vertical access only.

Do not use a ladder if workers need to go higher than the third highest rung.

A ladder is not to be used to gain height above the protected edge of a scaffold or an elevating work platform.

Only one person at a time may use a ladder. If a ladder's base or top is being held by a worker, that worker is not to do other work while there is a person on the ladder.

No person may be on a ladder when it is being moved to a new work location.

When climbing or descending a ladder, workers:

- are to face the normal climbing side of the ladder
- are to have at least three limbs (i.e. both hands and 1 foot, or 1 hand and both feet) in contact with the ladder at all times) (Figure 5)
- may grip the stiles or rungs
- are not to carry objects in their hands.

Tools are to be carried in a tool belt, holster or pouch, not in the hands.

While on a ladder, workers:

- are not to "walk" the ladder ("walk" means cause the ladder to move by moving one's body at the top of the ladder, thus lifting the ends of the stiles alternately)
- are not to climb so that their feet are higher than the third highest rung
- are not to reach to either side or away from the ladder, except to hold a stable supporting structure.

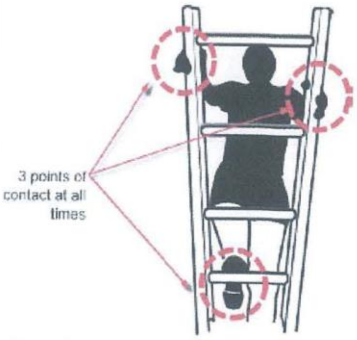


Figure 5 **Example of correct contact between user and ladder**

Working near electrical equipment	**Ladder type**	Non-conductive ladders are to be used for working near electrical equipment. Metal ladders or metal reinforced ladders are not to be used for any work that requires the ladder to be placed within 6 m of exposed high voltage electrical equipment or the 1500 volt overhead wiring.
	Construction	Timber ladders may be reinforced with pultruded fibre-reinforced plastic (FRP) rod to AS 1892.2. Timber ladders may use technology not consistent with AS 1892.2 provided that the ladder has the written approval of the Principal Electrical Engineer.
		☞ ***Note*** *Wire reinforced stiles are not acceptable. Reinforced plastic ladders are to comply with to AS/NZS 1892.3.*
	Conductivity	Stiles are to be non-conductive. Ladders can have metal brackets or rungs and other metal fittings that are required for securing or reinforcement and that do NOT effectively reduce the longitudinal nonconductive properties of the ladder.
	Markings	The ladder stiles are to be marked according to the requirements of AS 1892. These markings are to include all of the following: • the name of manufacturer • the specification number • the length or maximum extended length of the ladder in metres • the load capacity of the ladder • in the case of timber ladders manufactured to AS 1892.2: • the letters "MSG" or • the words "Mechanically Stress Graded" followed by the letters "B", "G" or "P" or • marked with the corresponding colours "Black", "Green" or "Purple".
		☞ ***Note*** *The marking requirement does not apply to ladders purchased before 1997.*
	Pole chain	A ladder that is to be placed against a wood pole or similar rounded support is to be fitted with a chain between the upper ends of the ladder stiles. This chain is the point of support for the ladder.
	Head and base ropes	If the ladder is to be used against a pole, tree, lighting column, signal post or similar, or against the 1500 V overhead wiring, a length of three strand hawser-laid rope at least 12 mm diameter, (as per AS 4142.2) is to be secured: • to one stile at a point not above the uppermost rung for the head rope • to one stile approximately 1 m from the ground, to secure the base.
		☞ ***Note*** *Refer to the Working Around Electrical Equipment guide when working near 1500 volt overhead wiring*

Using fall prevention equipment

If a worker is at a height of more than 2m, an appropriate harness and safety lines is to be provided.

Pole straps may be necessary while working from portable ladders.

They are to be inspected regularly, including at least daily when in use.

For more instructions, refer to:

- Physical Restraint Systems (Pole Straps) SWI.

Figure 6 Example of the use of pole straps

Training

People working at heights from ladders are to be competent in both the work to be done and the use of ladders. They are to also understand any potential effects of the work process on the access system. For example, a wet process can make a ladder slippery; a process using chemical solvents can damage a fibreglass ladder, a metal ladder is a danger when used in the vicinity of an electrical hazard. Training in the selection of equipment is to address these issues.

Training can take place on the job or in a specialized training environment. People being trained are to be supervised by a person competent in the skill being learned.

Competency in skills that are not practiced is lost in time. Where competency is not maintained through practice, the skill is to be revised and assessed prior to the person again being considered competent in accordance with training requirements defined in the Working at Heights guide.

Care and maintenance

Avoid dropping ladders or damaging them in any other way. Damage to the stiles can weaken the ladder and/or cause a hand injury hazard from splinters.

Normally water is sufficient to remove mud and dirt from a ladder. If the ladder becomes contaminated with a substance that requires a more powerful cleaner, take care to make sure that the neither the substance to be removed nor the solvent damages the ladder.

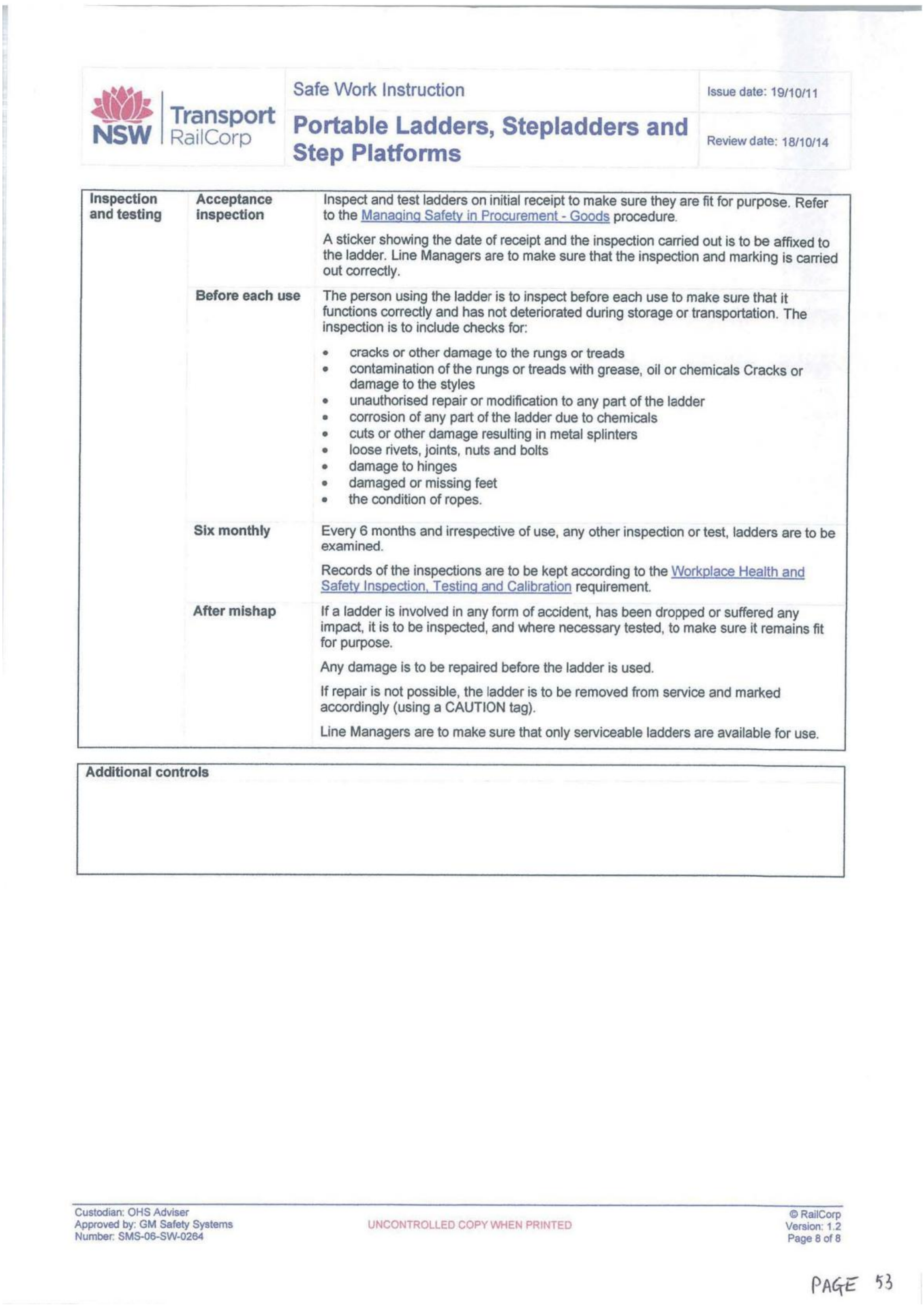
In particular, consideration is to be given to possible damage to the lacquer coating on timber ladders as this is essential to exclude water to maintain the insulating properties of the ladder and to prevent decay of the timber.

Never paint timber ladders. If a preservative is used, it is to be transparent during the life of the ladder to enable visual inspections to detect deterioration or defects.

Storage and transport a

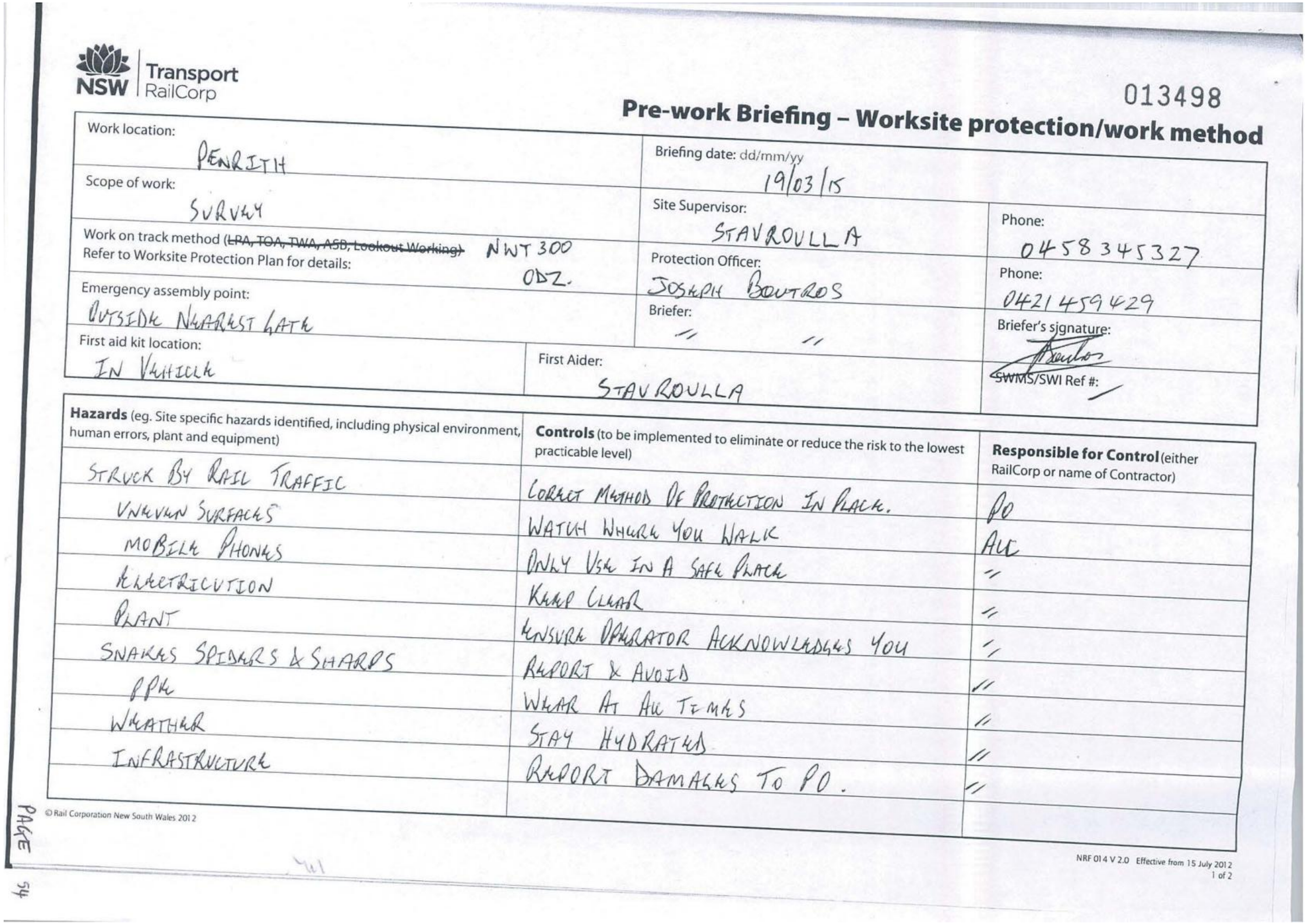
Ladders are to be:

- regularly checked for deterioration
- kept out of the weather, where possible, because water and sunlight can damage them
- stored in a proper and safe manner:
  - so that no stress is placed on them
  - either vertically or horizontally, and are not to have other material stacked on them
  - ladders stored horizontally are to be provided with adequate support to prevent sagging
- transported in such a way that they are not damaged:
  - if carried in a vehicle, the ladder is to be strapped to prevent movement, and supported to prevent sagging
  - if the ladder is carried by hand, proper manual handling procedures are to be used.



Inspection and testing	**Acceptance inspection**	Inspect and test ladders on initial receipt to make sure they are fit for purpose. Refer to the Managing Safety in Procurement - Goods procedure. A sticker showing the date of receipt and the inspection carried out is to be affixed to the ladder. Line Managers are to make sure that the inspection and marking is carried out correctly.
	Before each use	The person using the ladder is to inspect before each use to make sure that it functions correctly and has not deteriorated during storage or transportation. The inspection is to include checks for: • cracks or other damage to the rungs or treads • contamination of the rungs or treads with grease, oil or chemicals Cracks or damage to the styles • unauthorised repair or modification to any part of the ladder • corrosion of any part of the ladder due to chemicals • cuts or other damage resulting in metal splinters • loose rivets, joints, nuts and bolts • damage to hinges • damaged or missing feet • the condition of ropes.
	Six monthly	Every 6 months and irrespective of use, any other inspection or test, ladders are to be examined. Records of the inspections are to be kept according to the Workplace Health and Safety Inspection, Testing and Calibration requirement.
	After mishap	If a ladder is involved in any form of accident, has been dropped or suffered any impact, it is to be inspected, and where necessary tested, to make sure it remains fit for purpose. Any damage is to be repaired before the ladder is used. If repair is not possible, the ladder is to be removed from service and marked accordingly (using a CAUTION tag). Line Managers are to make sure that only serviceable ladders are available for use.

Additional controls



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Pre-work Briefing – Worksite protection/work method

Work location: PENRITH

Briefing date: dd/mm/yy 19/03/15

Scope of work: SURVEY

Site Supervisor: STAVROULLA

Phone: 0458345327

Work on track method (~~LPA, TOA, TWA, ASB, Lookout Working~~) NWT 300 ODZ.
Refer to Worksite Protection Plan for details:

Protection Officer: JOSEPH BOUTROS

Phone: 0421459429

Emergency assembly point: OUTSIDE NEAREST GATE

Briefer: " "

Briefer's signature:

First aid kit location: IN VEHICLE

First Aider: STAVROULLA

SWMS/SWI Ref #: —

Hazards (eg. Site specific hazards identified, including physical environment, human errors, plant and equipment)	**Controls** (to be implemented to eliminate or reduce the risk to the lowest practicable level)	**Responsible for Control** (either RailCorp or name of Contractor)
STRUCK BY RAIL TRAFFIC	CORRECT METHOD OF PROTECTION IN PLACE.	PO
UNEVEN SURFACES	WATCH WHERE YOU WALK	ALL
MOBILE PHONES	ONLY USE IN A SAFE PLACE	"
ELECTROCUTION	KEEP CLEAR	"
PLANT	ENSURE OPERATOR ACKNOWLEDGES YOU	"
SNAKES SPIDERS & SHARPS	REPORT & AVOID	"
PPE	WEAR AT ALL TIMES	"
WEATHER	STAY HYDRATED	"
INFRASTRUCTURE	REPORT DAMAGES TO PO.	"

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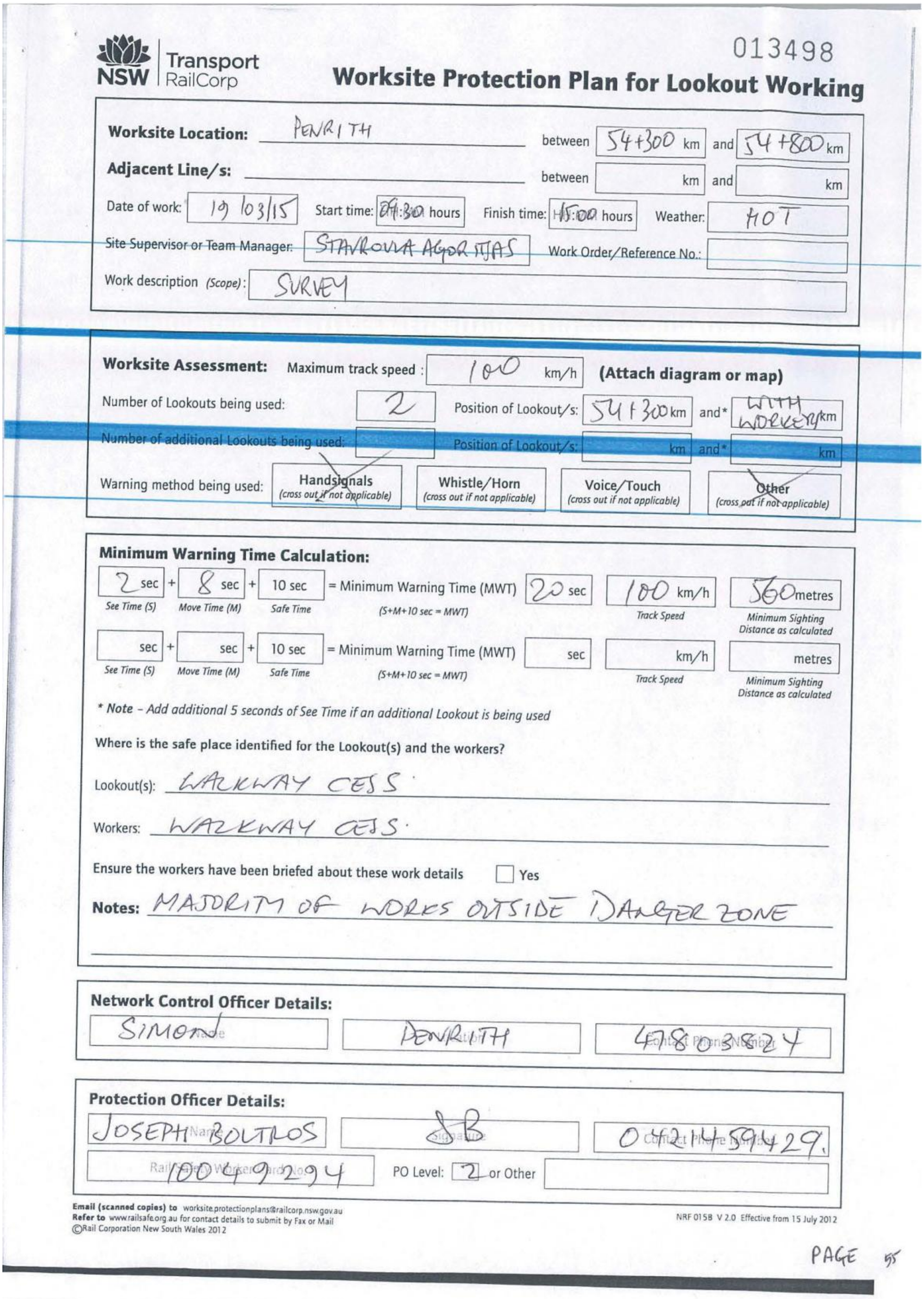

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013498

Worksite Protection Plan for Lookout Working

Worksite Location: PENRITH between 54+300 km and 54+800 km

Adjacent Line/s: between km and km

Date of work: 19/03/15 Start time: 09:30 hours Finish time: 15:00 hours Weather: HOT

Site Supervisor or Team Manager: STAVROULA AGORITSAS Work Order/Reference No.:

Work description *(Scope)*: SURVEY

Worksite Assessment: Maximum track speed: 100 km/h **(Attach diagram or map)**

Number of Lookouts being used: 2 Position of Lookout/s: 54+300 km and* WITH WORKERS km

Number of additional Lookouts being used: Position of Lookout/s: km and* km

Warning method being used: ~~**Handsignals** *(cross out if not applicable)*~~ **Whistle/Horn** *(cross out if not applicable)* **Voice/Touch** *(cross out if not applicable)* ~~**Other** *(cross out if not applicable)*~~

Minimum Warning Time Calculation:

2 sec	+	8 sec	+	10 sec	= Minimum Warning Time (MWT)	20 sec	100 km/h	560 metres
See Time (S)		*Move Time (M)*		*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*
sec	+	sec	+	10 sec	= Minimum Warning Time (MWT)	sec	km/h	metres
See Time (S)		*Move Time (M)*		*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*

** Note – Add additional 5 seconds of See Time if an additional Lookout is being used*

Where is the safe place identified for the Lookout(s) and the workers?

Lookout(s): WALKWAY CESS

Workers: WALKWAY CESS

Ensure the workers have been briefed about these work details ☐ Yes

Notes: MAJORITY OF WORKS OUTSIDE DANGER ZONE

Network Control Officer Details:

Name: SIMON
Location: PENRITH
Contact Phone Number: 4780 3824

Protection Officer Details:

Name: JOSEPH BOLTROS
Signature: JB
Contact Phone Number: 0421459429.
Rail Safety Worker Card No.: 1004 9294
PO Level: 2 or Other

Email (scanned copies) to worksite.protectionplans@railcorp.nsw.gov.au
Refer to www.railsafe.org.au for contact details to submit by Fax or Mail

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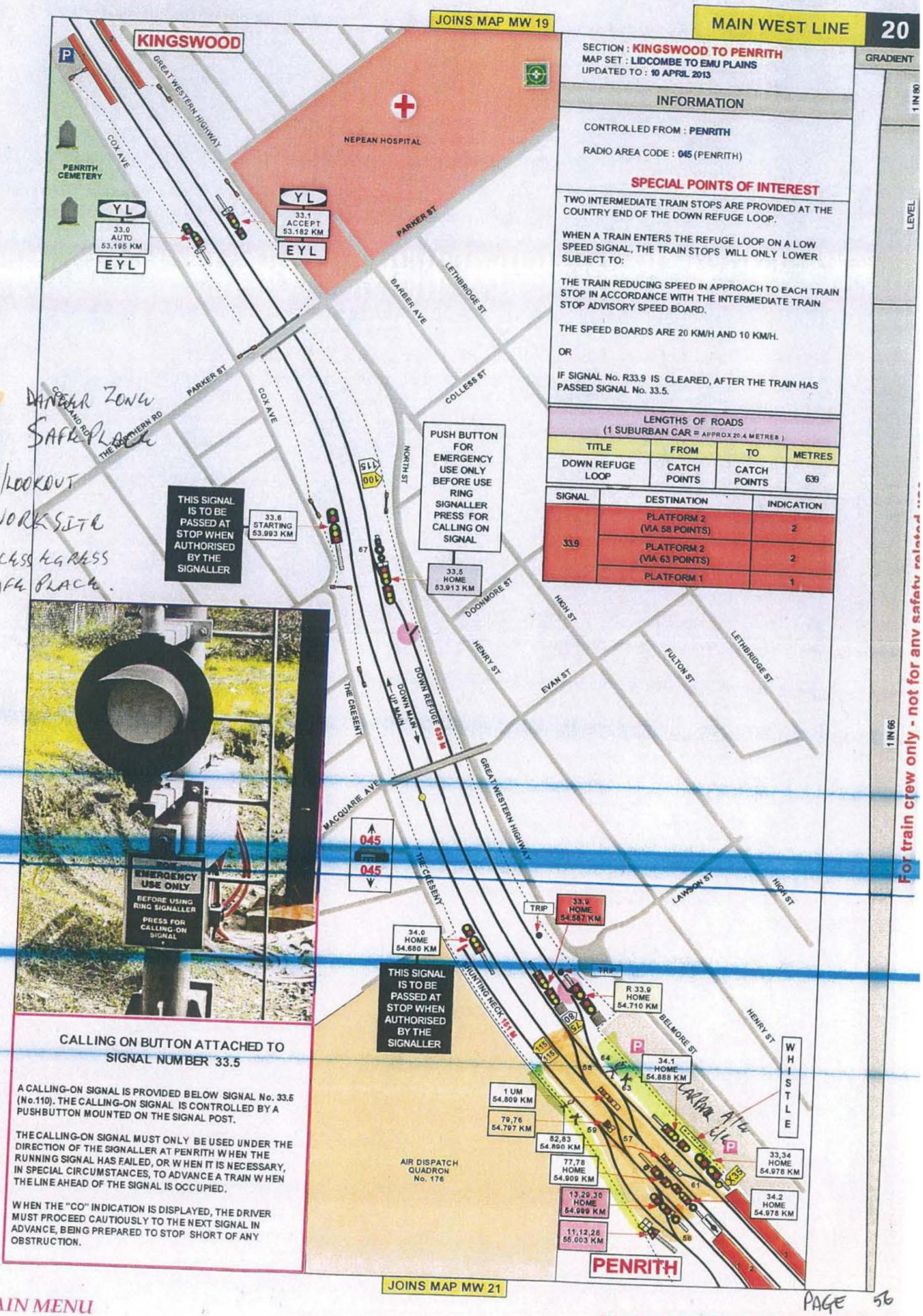
MAIN WEST LINE 20

SECTION : **KINGSWOOD TO PENRITH**
MAP SET : **LIDCOMBE TO EMU PLAINS**
UPDATED TO : **10 APRIL 2013**



DANGER ZONE
SAFE PLACE
PO/LOOKOUT
WORKSITE
ACCESS EGRESS
SAFE PLACE.

INFORMATION

CONTROLLED FROM : **PENRITH**

RADIO AREA CODE : **045** (PENRITH)

SPECIAL POINTS OF INTEREST

TWO INTERMEDIATE TRAIN STOPS ARE PROVIDED AT THE COUNTRY END OF THE DOWN REFUGE LOOP.

WHEN A TRAIN ENTERS THE REFUGE LOOP ON A LOW SPEED SIGNAL, THE TRAIN STOPS WILL ONLY LOWER SUBJECT TO:

THE TRAIN REDUCING SPEED IN APPROACH TO EACH TRAIN STOP IN ACCORDANCE WITH THE INTERMEDIATE TRAIN STOP ADVISORY SPEED BOARD.

THE SPEED BOARDS ARE 20 KM/H AND 10 KM/H.

OR

IF SIGNAL No. R33.9 IS CLEARED, AFTER THE TRAIN HAS PASSED SIGNAL No. 33.5.

LENGTHS OF ROADS
(1 SUBURBAN CAR = APPROX 20.4 METRES)

TITLE	FROM	TO	METRES
DOWN REFUGE LOOP	CATCH POINTS	CATCH POINTS	639

SIGNAL	DESTINATION	INDICATION
33.9	PLATFORM 2 (VIA 58 POINTS)	2
	PLATFORM 2 (VIA 63 POINTS)	2
	PLATFORM 1	1

CALLING ON BUTTON ATTACHED TO SIGNAL NUMBER 33.5

A CALLING-ON SIGNAL IS PROVIDED BELOW SIGNAL No. 33.5 (No.110). THE CALLING-ON SIGNAL IS CONTROLLED BY A PUSHBUTTON MOUNTED ON THE SIGNAL POST.

THE CALLING-ON SIGNAL MUST ONLY BE USED UNDER THE DIRECTION OF THE SIGNALLER AT PENRITH WHEN THE RUNNING SIGNAL HAS FAILED, OR WHEN IT IS NECESSARY, IN SPECIAL CIRCUMSTANCES, TO ADVANCE A TRAIN WHEN THE LINE AHEAD OF THE SIGNAL IS OCCUPIED.

WHEN THE "CO" INDICATION IS DISPLAYED, THE DRIVER MUST PROCEED CAUTIOUSLY TO THE NEXT SIGNAL IN ADVANCE, BEING PREPARED TO STOP SHORT OF ANY OBSTRUCTION.

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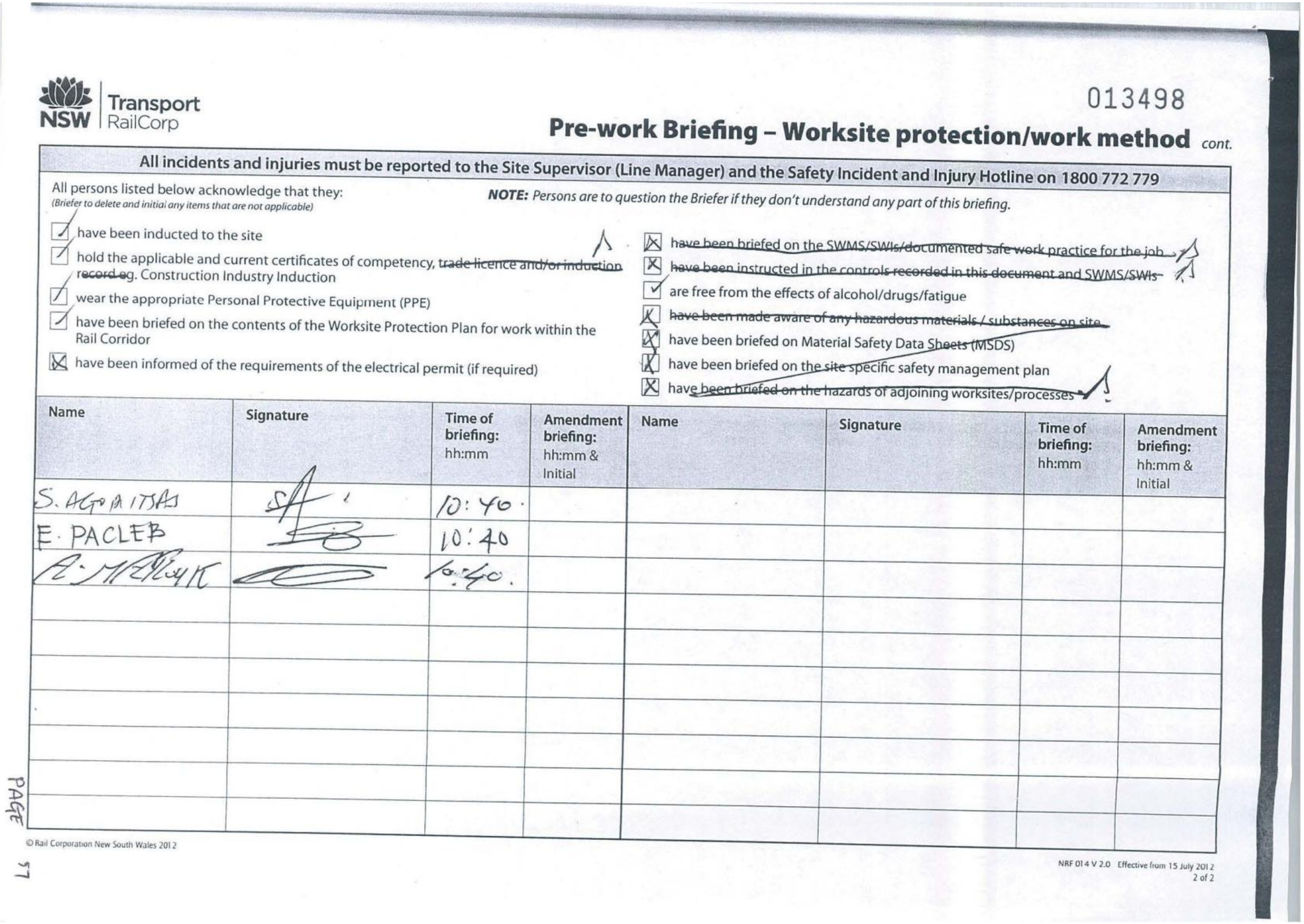

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Pre-work Briefing – Worksite protection/work method *cont.*

All incidents and injuries must be reported to the Site Supervisor (Line Manager) and the Safety Incident and Injury Hotline on 1800 772 779

All persons listed below acknowledge that they:
(Briefer to delete and initial any items that are not applicable)

NOTE: *Persons are to question the Briefer if they don't understand any part of this briefing.*

- ☑ have been inducted to the site
- ☑ hold the applicable and current certificates of competency, ~~trade licence and/or induction record~~ eg. Construction Industry Induction
- ☑ wear the appropriate Personal Protective Equipment (PPE)
- ☑ have been briefed on the contents of the Worksite Protection Plan for work within the Rail Corridor
- ☒ have been informed of the requirements of the electrical permit (if required)
- ☒ ~~have been briefed on the SWMS/SWIs/documented safe work practice for the job~~
- ☒ ~~have been instructed in the controls recorded in this document and SWMS/SWIs~~
- ☑ are free from the effects of alcohol/drugs/fatigue
- ☒ ~~have been made aware of any hazardous materials / substances on site~~
- ☒ have been briefed on Material Safety Data Sheets (MSDS)
- ☒ have been briefed on the site specific safety management plan
- ☒ have ~~been briefed on the hazards of adjoining worksites/processes~~

Name	Signature	Time of briefing: hh:mm	Amendment briefing: hh:mm & Initial	Name	Signature	Time of briefing: hh:mm	Amendment briefing: hh:mm & Initial
S. AGORAITSAS		10:40.					
E. PACLEB		10:40					
A. MELNYK		10:40.					

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Transport
NSW RailCorp

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Protection Officer's Diary

Date	Time	Notes
19/03/15	08·30	PWB & WPP.
19/03/15	08·45	RANG CSN S/T STEVE OBTAINED 190058
		WORKING OUTSIDE DANGER ZONE
		CITY SIDE OF PENRITH.
	10-35	RANG BOX S/T SIMON. WOD2. SIGNED ON 1
	12-00	LUNCH
	12-45	RESUMED
	14-26	RANG BOX ALLCLEAR

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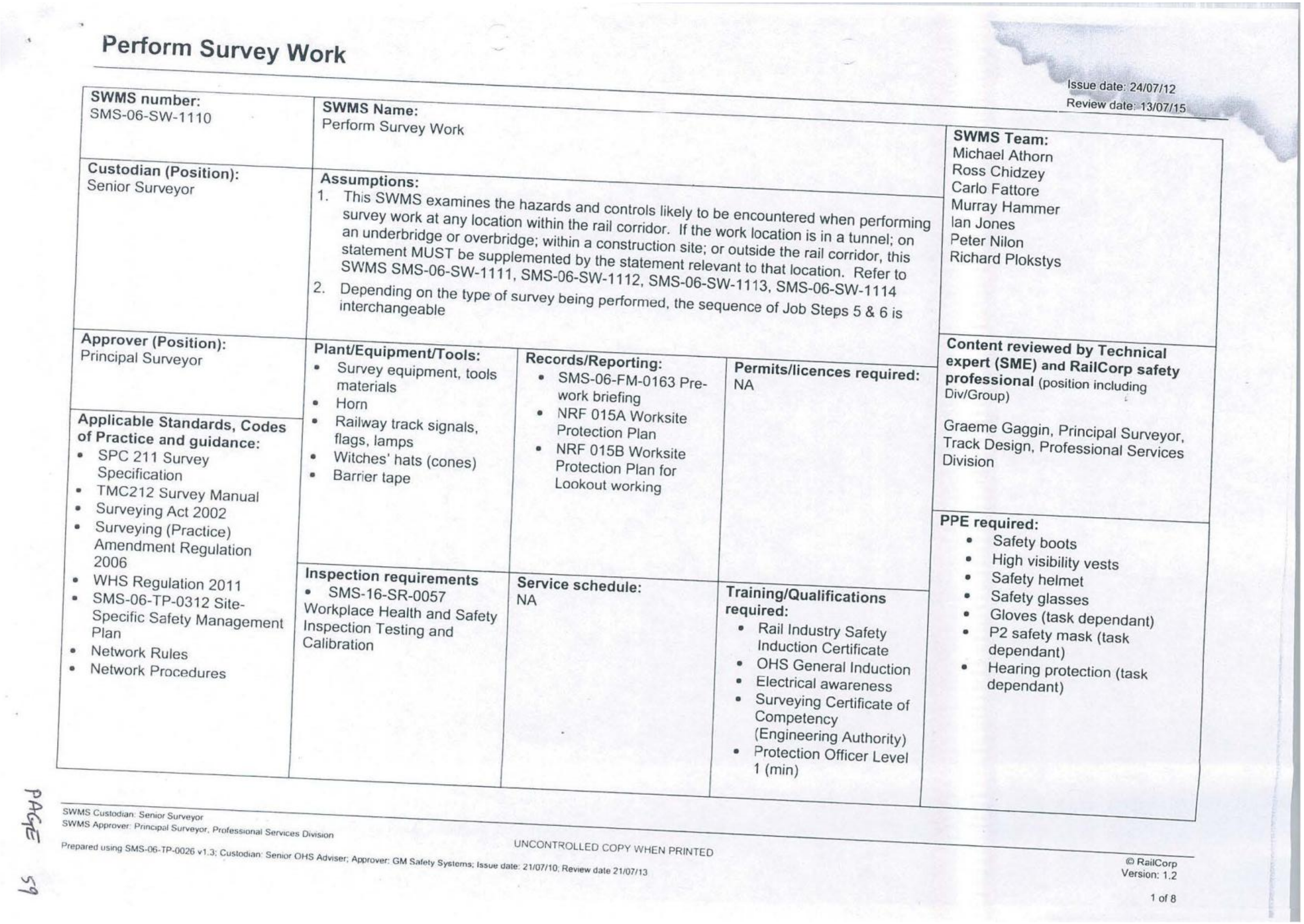

Perform Survey Work

Issue date: 24/07/12
Review date: 13/07/15

SWMS number:
SMS-06-SW-1110

SWMS Name:
Perform Survey Work

SWMS Team:
Michael Athorn
Ross Chidzey
Carlo Fattore
Murray Hammer
Ian Jones
Peter Nilon
Richard Plokstys

Custodian (Position):
Senior Surveyor

Assumptions:

1. This SWMS examines the hazards and controls likely to be encountered when performing survey work at any location within the rail corridor. If the work location is in a tunnel; on an underbridge or overbridge; within a construction site; or outside the rail corridor, this statement MUST be supplemented by the statement relevant to that location. Refer to SWMS SMS-06-SW-1111, SMS-06-SW-1112, SMS-06-SW-1113, SMS-06-SW-1114
2. Depending on the type of survey being performed, the sequence of Job Steps 5 & 6 is interchangeable

Approver (Position):
Principal Surveyor

Applicable Standards, Codes of Practice and guidance:

- SPC 211 Survey Specification
- TMC212 Survey Manual
- Surveying Act 2002
- Surveying (Practice) Amendment Regulation 2006
- WHS Regulation 2011
- SMS-06-TP-0312 Site-Specific Safety Management Plan
- Network Rules
- Network Procedures

Plant/Equipment/Tools:

- Survey equipment, tools materials
- Horn
- Railway track signals, flags, lamps
- Witches' hats (cones)
- Barrier tape

Records/Reporting:

- SMS-06-FM-0163 Pre-work briefing
- NRF 015A Worksite Protection Plan
- NRF 015B Worksite Protection Plan for Lookout working

Permits/licences required:
NA

Content reviewed by Technical expert (SME) and RailCorp safety professional (position including Div/Group)

Graeme Gaggin, Principal Surveyor, Track Design, Professional Services Division

Inspection requirements

- SMS-16-SR-0057 Workplace Health and Safety Inspection Testing and Calibration

Service schedule:
NA

Training/Qualifications required:

- Rail Industry Safety Induction Certificate
- OHS General Induction
- Electrical awareness
- Surveying Certificate of Competency (Engineering Authority)
- Protection Officer Level 1 (min)

PPE required:

- Safety boots
- High visibility vests
- Safety helmet
- Safety glasses
- Gloves (task dependant)
- P2 safety mask (task dependant)
- Hearing protection (task dependant)

SWMS Custodian: Senior Surveyor
SWMS Approver: Principal Surveyor, Professional Services Division

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Version: 1.2

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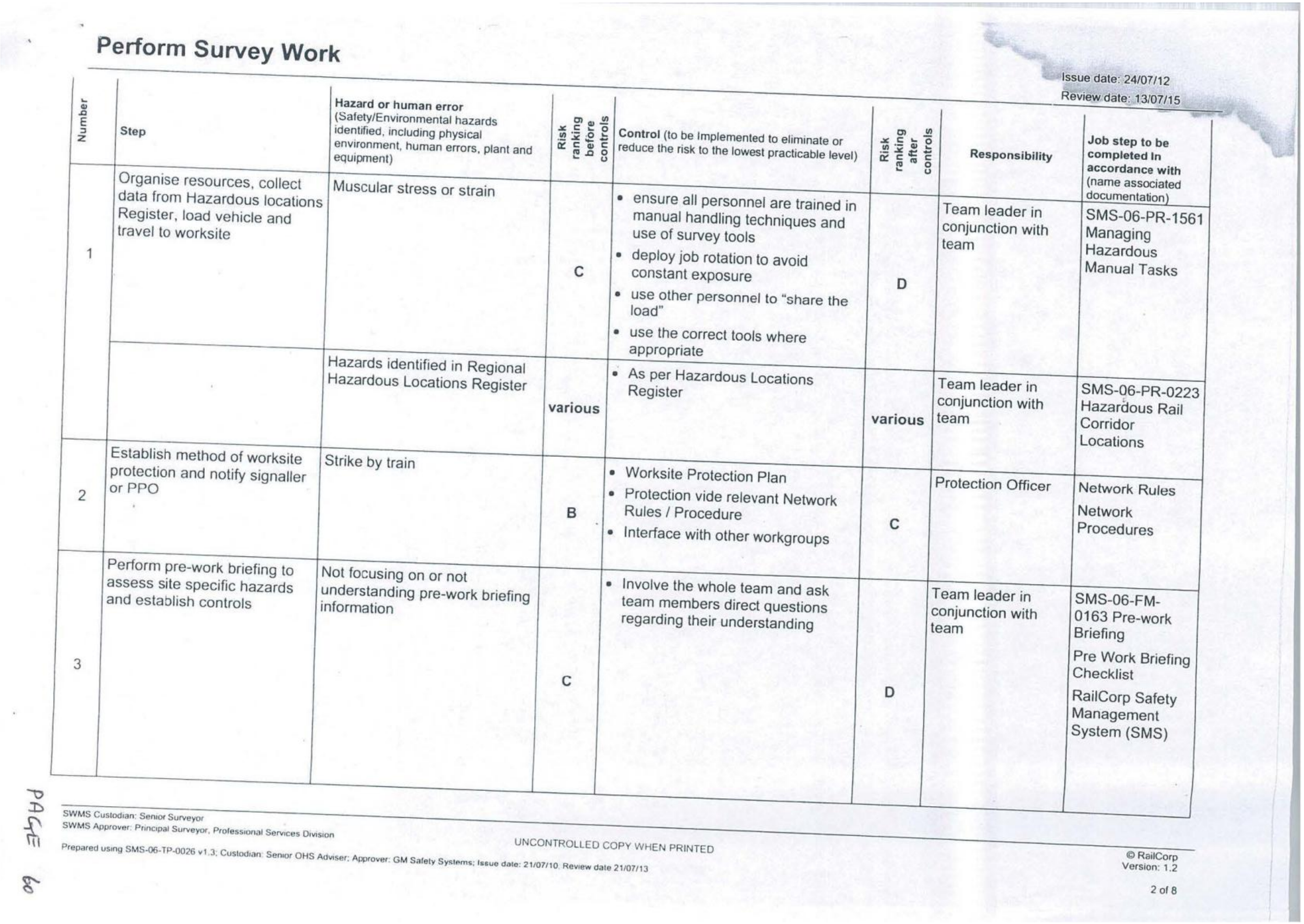

Perform Survey Work

Issue date: 24/07/12
Review date: 13/07/15

Number	Step	Hazard or human error (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Control (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	Risk ranking after controls	Responsibility	Job step to be completed In accordance with (name associated documentation)
1	Organise resources, collect data from Hazardous locations Register, load vehicle and travel to worksite	Muscular stress or strain	C	• ensure all personnel are trained in manual handling techniques and use of survey tools • deploy job rotation to avoid constant exposure • use other personnel to "share the load" • use the correct tools where appropriate	D	Team leader in conjunction with team	SMS-06-PR-1561 Managing Hazardous Manual Tasks
		Hazards identified in Regional Hazardous Locations Register	various	• As per Hazardous Locations Register	various	Team leader in conjunction with team	SMS-06-PR-0223 Hazardous Rail Corridor Locations
2	Establish method of worksite protection and notify signaller or PPO	Strike by train	B	• Worksite Protection Plan • Protection vide relevant Network Rules / Procedure • Interface with other workgroups	C	Protection Officer	Network Rules Network Procedures
3	Perform pre-work briefing to assess site specific hazards and establish controls	Not focusing on or not understanding pre-work briefing information	C	• Involve the whole team and ask team members direct questions regarding their understanding	D	Team leader in conjunction with team	SMS-06-FM-0163 Pre-work Briefing Pre Work Briefing Checklist RailCorp Safety Management System (SMS)

SWMS Custodian: Senior Surveyor
SWMS Approver: Principal Surveyor, Professional Services Division

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Version: 1.2

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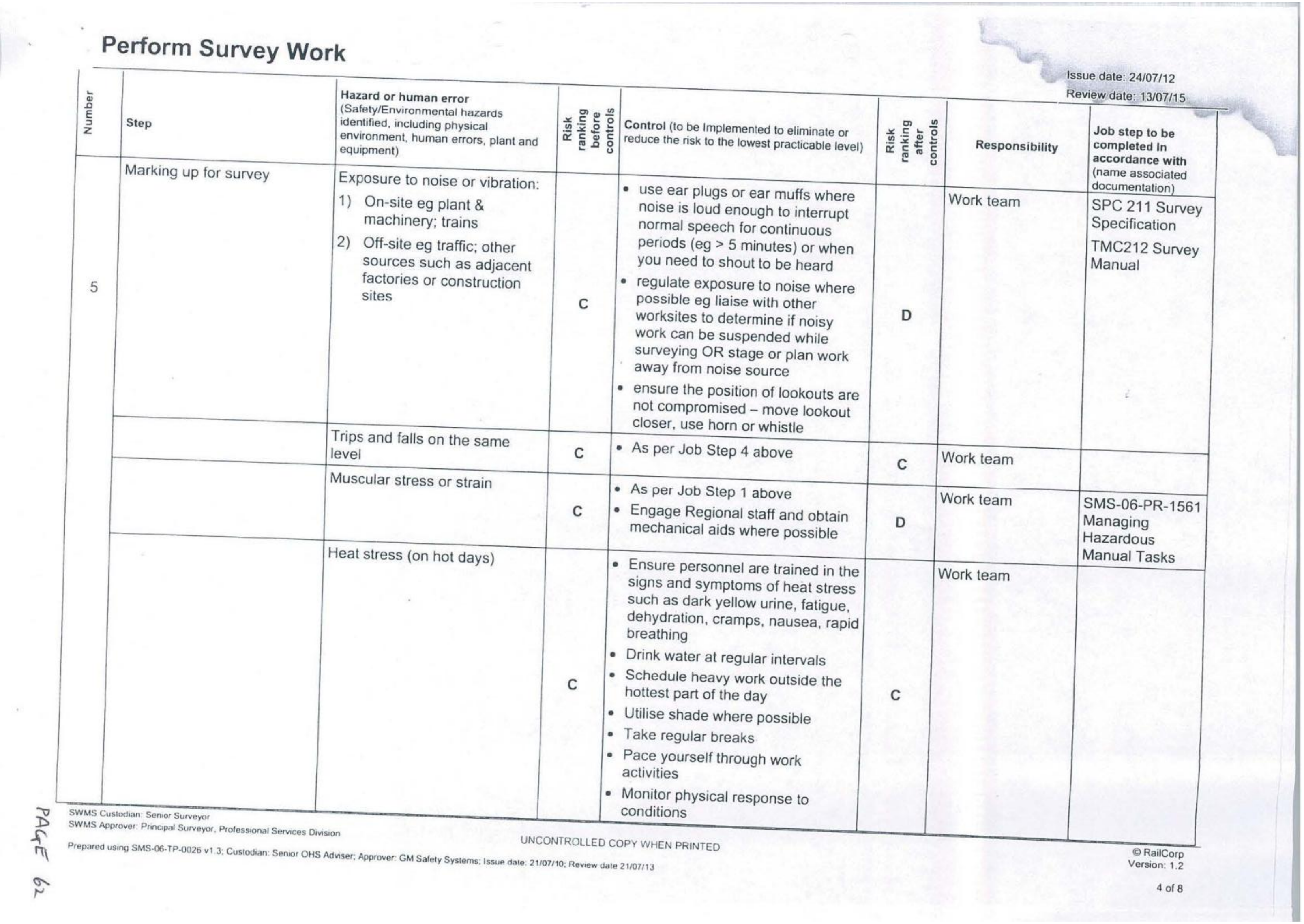
Perform Survey Work

Number	Step	**Hazard or human error** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	**Risk ranking before controls**	**Control** (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	**Risk ranking after controls**	**Responsibility**	**Job step to be completed In accordance with** (name associated documentation)
4	Unload equipment and transfer to worksite	Muscular stress or strain	C	• As per Job Step 1 above	D	Work team	
	Unload equipment and transfer to worksite	Trips and falls on the same level	C	• Wear appropriate footwear – safety boots, safety gum boots • Ensure the worksite is clear of debris • Position tools, equipment and materials in a safe place clear of walkways, refuges and vehicular access routes • Identify slippery surfaces, wet locations, grease pots etc within the worksite • Be aware of the position of the rails and track side equipment • Ensure lighting is adequate – use torches in tunnels, at night and in other dark locations • Avoid carrying loads on steep embankments • Avoid steep ballast shoulders • Do not jump off batters or across drainage controls or from platforms • Share or minimise loads • Walk slowly and purposefully through areas of high risk	C	Work team	SMS-06-GD-0323 Personal Protective Equipment



Perform Survey Work

Issue date: 24/07/12
Review date: 13/07/15

Number	Step	Hazard or human error (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Control (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	Risk ranking after controls	Responsibility	Job step to be completed In accordance with (name associated documentation)
5	Marking up for survey	Exposure to noise or vibration: 1) On-site eg plant & machinery; trains 2) Off-site eg traffic; other sources such as adjacent factories or construction sites	C	• use ear plugs or ear muffs where noise is loud enough to interrupt normal speech for continuous periods (eg > 5 minutes) or when you need to shout to be heard • regulate exposure to noise where possible eg liaise with other worksites to determine if noisy work can be suspended while surveying OR stage or plan work away from noise source • ensure the position of lookouts are not compromised – move lookout closer, use horn or whistle	D	Work team	SPC 211 Survey Specification TMC212 Survey Manual
		Trips and falls on the same level	C	• As per Job Step 4 above	C	Work team	
		Muscular stress or strain	C	• As per Job Step 1 above • Engage Regional staff and obtain mechanical aids where possible	D	Work team	SMS-06-PR-1561 Managing Hazardous Manual Tasks
		Heat stress (on hot days)	C	• Ensure personnel are trained in the signs and symptoms of heat stress such as dark yellow urine, fatigue, dehydration, cramps, nausea, rapid breathing • Drink water at regular intervals • Schedule heavy work outside the hottest part of the day • Utilise shade where possible • Take regular breaks • Pace yourself through work activities • Monitor physical response to conditions	C	Work team	

SWMS Custodian: Senior Surveyor
SWMS Approver: Principal Surveyor, Professional Services Division

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Version: 1.2

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Perform Survey Work

Number	Step	**Hazard or human error** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	**Control** (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	Risk ranking after controls	Responsibility	**Job step to be completed In accordance with** (name associated documentation)
5 ctd		Exposure to UV radiation	C	• Use sunscreen and replace regularly • Stage or plan work to take advantage of shade where possible • Tinted Safety glasses to be worn when looking upwards (such as for OHW surveys)	D	Work team	
		Snake bite, insect bites and stings	C	• Identify locations of high risk - long grass; near culverts and dams; under rocks, sleepers, rail logs and burrows • Wear gloves where appropriate • Walk "heavily" • Don't enter areas you cannot see properly	C	Work team	
		Distraction of team member by mobile phone, leading to an unsafe situation	C	• Use of mobile phones must be specifically discussed in the pre-work briefing. Depending on the site and varying roles of personnel, phones other than that of the protection officer may need to be turned off when working. • If taking a call work must cease. • Use phone only when in a safe place	D	Work team	
		Contact with asbestos encountered on site	C	• Consult the Regional Hazardous Locations Register • Do not disturb asbestos materials encountered on site • Report the location of asbestos found to the local Region	D	Work team	SMS-06-PR-1565 Managing Hazardous Materials Register

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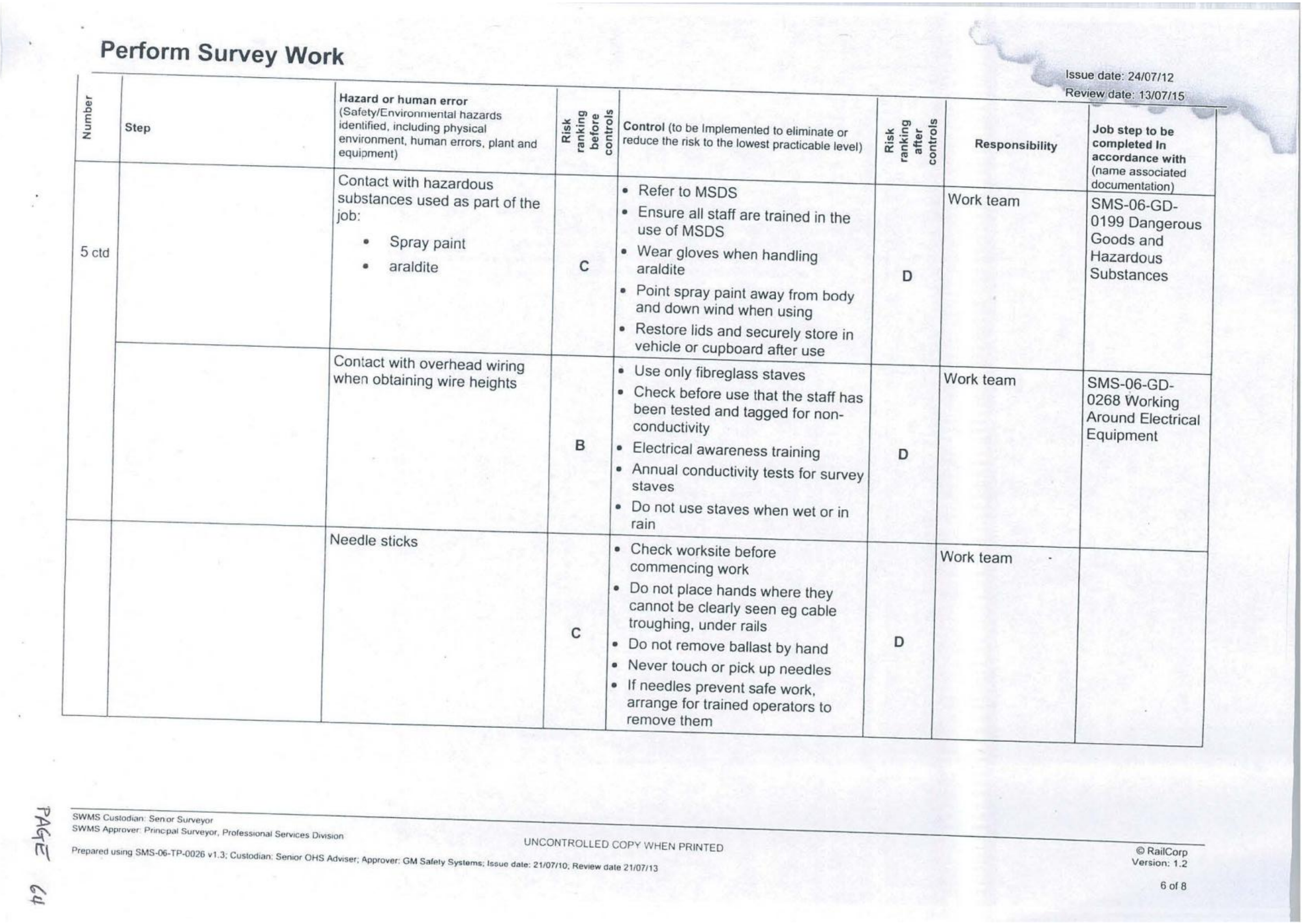


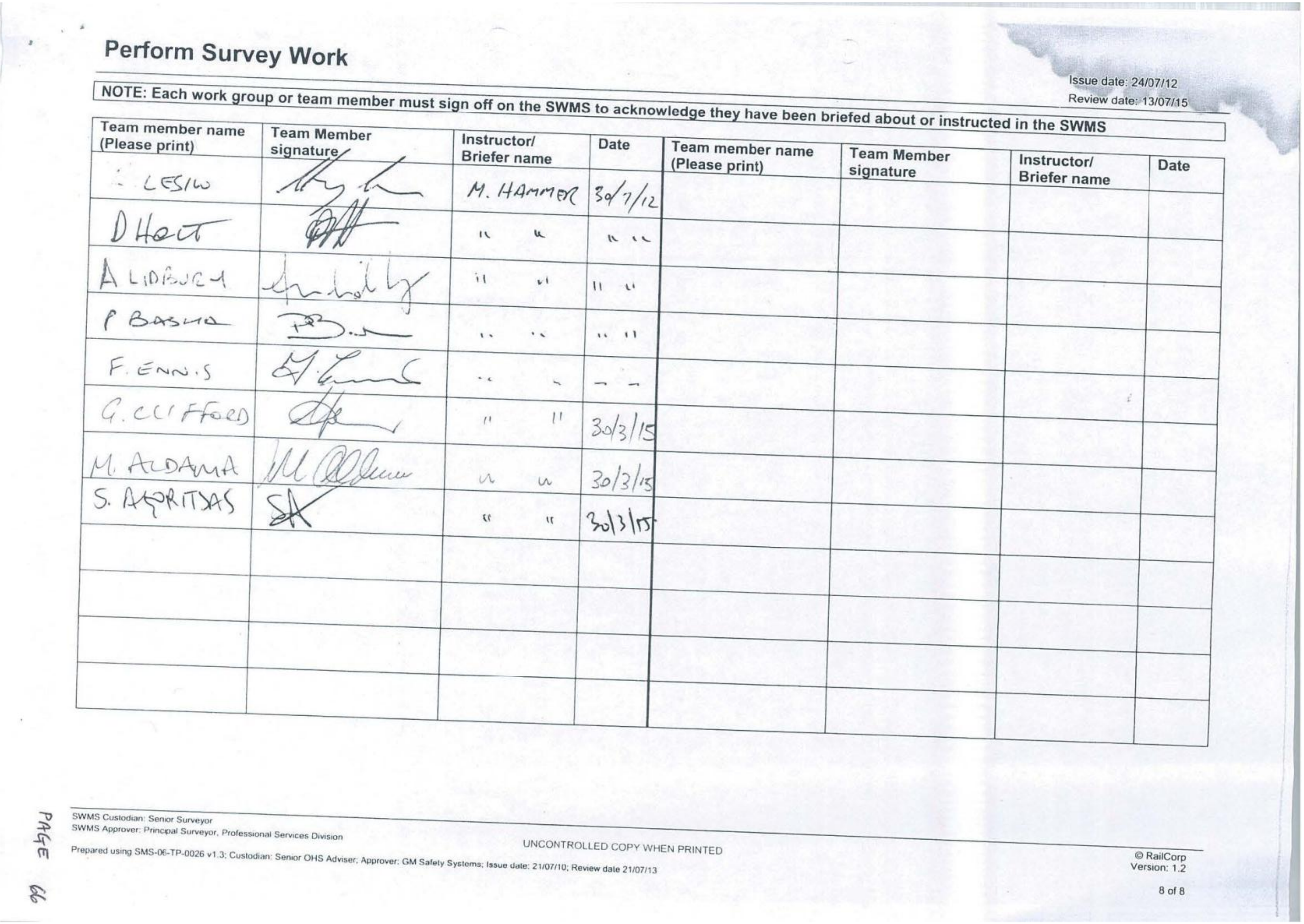
Perform Survey Work

Issue date: 24/07/12
Review date: 13/07/15

Number	Step	Hazard or human error (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Control (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	Risk ranking after controls	Responsibility	Job step to be completed In accordance with (name associated documentation)
5 ctd		Contact with hazardous substances used as part of the job: • Spray paint • araldite	C	• Refer to MSDS • Ensure all staff are trained in the use of MSDS • Wear gloves when handling araldite • Point spray paint away from body and down wind when using • Restore lids and securely store in vehicle or cupboard after use	D	Work team	SMS-06-GD-0199 Dangerous Goods and Hazardous Substances
		Contact with overhead wiring when obtaining wire heights	B	• Use only fibreglass staves • Check before use that the staff has been tested and tagged for non-conductivity • Electrical awareness training • Annual conductivity tests for survey staves • Do not use staves when wet or in rain	D	Work team	SMS-06-GD-0268 Working Around Electrical Equipment
		Needle sticks	C	• Check worksite before commencing work • Do not place hands where they cannot be clearly seen eg cable troughing, under rails • Do not remove ballast by hand • Never touch or pick up needles • If needles prevent safe work, arrange for trained operators to remove them	D	Work team	

Perform Survey Work

Number	Step	**Hazard or human error** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	**Risk ranking before controls**	**Control** (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	**Risk ranking after controls**	**Responsibility**	**Job step to be completed In accordance with** (name associated documentation)
5 ctd		Pedestrian traffic around platforms (pedestrians can be a hazard and YOU can be a hazard to pedestrians)	C	• Where practical, control pedestrian access by using witches hats, barriers or barrier tape • Utilise lookouts • Position tools equipment and materials clear of pedestrian walkways • Where it is not practical to control pedestrian traffic due to large numbers or busy platforms, plan work for less busy periods eg night work or possessions	D	Work team	
		Incorrect use of hand drill	C	• Use only battery powered hand drill • Use hand drill according to manufacturers instruction • Ensure chuck is firmly secured • Hold drill firmly when drilling • Wear safety glasses	D	Work team	
		Strike from swinging hammer or brush hook	B	• Wear PPE • Team members to remain clear of hammer or brush hook user	C	Work team	
6	Collect survey data	As per Job Step 5 above		• As per Job Step 5 above		Work team	As per Step 5
7	Transfer equipment to vehicle	Muscular stress or strain	C	• As per Job Step 1 above	D	Work team	SMS-06-PR-1561 Managing Hazardous Manual Tasks
8	Remove worksite protection and notify signaller or PPO of completion	Strike by train	B	• Worksite Protection Plan • Protection vide relevant Network Rule and/or Procedure	C	Protection Officer	Network Rules Network Procedures



Perform Survey Work

Issue date: 24/07/12
Review date: 13/07/15

NOTE: Each work group or team member must sign off on the SWMS to acknowledge they have been briefed about or instructed in the SWMS

Team member name (Please print)	Team Member signature	Instructor/ Briefer name	Date	Team member name (Please print)	Team Member signature	Instructor/ Briefer name	Date
LESIW		M. HAMMER	30/7/12				
D HOLT		" "	" "				
A LIDBURY		" "	" "				
P BASHA		" "	" "				
F. ENNIS		" "	- -				
G. CLIFFORD		" "	30/3/15				
M. ALDAMA		" "	30/3/15				
S. AKORITSAS		" "	30/3/15				

SWMS Custodian: Senior Surveyor
SWMS Approver: Principal Surveyor, Professional Services Division
Prepared using SMS-06-TP-0026 v1.3; Custodian: Senior OHS Adviser; Approver: GM Safety Systems; Issue date: 21/07/10; Review date 21/07/13

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Version: 1.2

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Perform Survey Work Outside The Rail Corridor

Issue date: 24/07/12
Review date: 13/07/15

SWMS number:
SMS-06-SW-1114

SWMS Name:
Perform Survey Work Outside the Rail Corridor

SWMS Team:
Michael Athorn
Ross Chidzey
Carlo Fattore
Murray Hammer
Ian Jones
Peter Nilon
Richard Plokstys
David Brown

Custodian (Position):
Senior Surveyor

Assumptions:

1. This statement examines the hazards and controls likely to be encountered when performing survey work outside the rail corridor. This statement is a supplement to SWMS SMS-06-SW-1110 Perform Survey Work and MUST be used in conjunction with that SWMS which outlines generic risks for performing survey work in any location.
2. Job Steps 1 to 4 and 7 to 8 are obtained from SMS-06-SW-1110
3. Job Step 2 (vide SMS-06-SW-1110) – "Establish method of worksite protection" would generally not apply to this SWMS
4. Depending on the type of survey being performed, the sequence of Job Steps 5 & 6 is interchangeable

Content reviewed by Technical expert (SME) and RailCorp safety professional (position including Div/Group)

Graeme Gaggin, Principal Surveyor, Track Design, Professional Services Division

Approver (Position):
Principal Surveyor

Plant/Equipment/Tools:

- Survey equipment, hand tools and materials
- Witches' hats (cones)
- Barrier tape

Records/Reporting:

- SMS-06-FM-0163 Pre-work briefing

Permits/licences required:
NA

Applicable Standards, Codes of Practice and guidance:

- SPC 211 Survey Specification
- TMC212 Survey Manual
- Surveying Act 2002
- Surveying (Practice) Amendment Regulation 2006
- WHS Regulation 2011
- SMS-06-TP-0312 Site-Specific Safety Management Plan
- RTA Traffic Control at Worksites
- SMS-06-GD-1574 Managing Construction Hazards

Inspection requirements

- SMS-16-SR-0057 Workplace Health and Safety Inspection Testing and Calibration

Service schedule:
NA

Training/Qualifications required:

- OHS General Induction
- Surveying Certificate of Competency (Engineering Authority)

PPE required:

- Safety boots
- High visibility vests
- Safety helmet (task dependant)
- Safety glasses (task dependant)
- P2 safety mask (task dependant)
- Hearing protection (task dependant)

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Perform Survey Work Outside The Rail Corridor

Issue date: 24/07/12
Review date: 13/07/15

Number	Step	**Hazard or human error** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	**Control** (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	Risk ranking after controls	**Responsibility**	**Job step to be completed in accordance with** (name associated documentation)
5	Marking up for survey	As identified in SWMS SMS-06-SW-1110 Perform Survey Work		As identified in SWMS SMS-06-SW-1110 Perform Survey Work		Team Leader	SPC 211 Survey Specification TMC212 Survey Manual
		Road traffic	B	• Wear high visibility safety vest • Perform and document (in pre-work brief) a risk assessment to determine areas of work, traffic conditions and access requirements to the carriageway • Use extreme caution when crossing or working on the road carriageway as car paths are unpredictable • When performing work on the roadside (between boundary and nearest road shoulder) use witches hats around instrument if pedestrian traffic has potential to impact • Utilise lookouts when crossing road carriageway or performing intermittent work on the carriageway • Utilise traffic lights where available • Where traffic volumes are such that there are no intermittent gaps, and/or signposted speed is greater than 60 kph and the carriageway needs to be accessed, arrange with Project Manager for formal Traffic Control	C	Work team	RTA Traffic Control at Worksites SMS-06-GD-1574 Managing Construction Hazards

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Perform Survey Work Outside The Rail Corridor

Number	Step	**Hazard or human error** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	**Risk ranking before controls**	**Control** (to be Implemented to eliminate or reduce the risk to the lowest practicable level)	**Risk ranking after controls**	**Responsibility**	**Job step to be completed In accordance with** (name associated documentation)
5 ctd		Pedestrian traffic – pedestrians can be a hazard and YOU can be a hazard to pedestrians	C	• Wear high visibility safety vest • Where practical control pedestrian access by using witches hats or barriers • Utilise lookouts • Position tools equipment and materials clear of pedestrian walkways	D	Work team	RTA Traffic Control at Worksites SMS-06-GD-1574 Managing Construction Hazards
6	Collect survey data	As per Job Step 5 above		• As per Job Step 5 above		Team Leader	As per Step 5

Perform Survey Work Outside The Rail Corridor

Issue date: 24/07/12
Review date: 13/07/15

NOTE: Each work group or team member must sign off on the SWMS to acknowledge they have been briefed about or instructed in the SWMS

Team member name (Please print)	Team Member signature	Instructor/ Briefer name	Date	Team member name (Please print)	Team Member signature	Instructor/ Briefer name	Date
H. LESIW		M. HAMMER	30/7/12				
D. HOLT		" "	" "				
A. LIDBURY		" "	" "				
P Basha		" "	" "				
F. ENNIS		" "	— —				
G. CLIFFORD		" "	30/3/15				
M. ALDAMA		" "	30/3/15				
S. ALGORITSAS		" "	30/3/15.				

SWMS Custodian: Senior Surveyor
SWMS Approver: Principal Surveyor, Professional Services Division

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Version: 1.2

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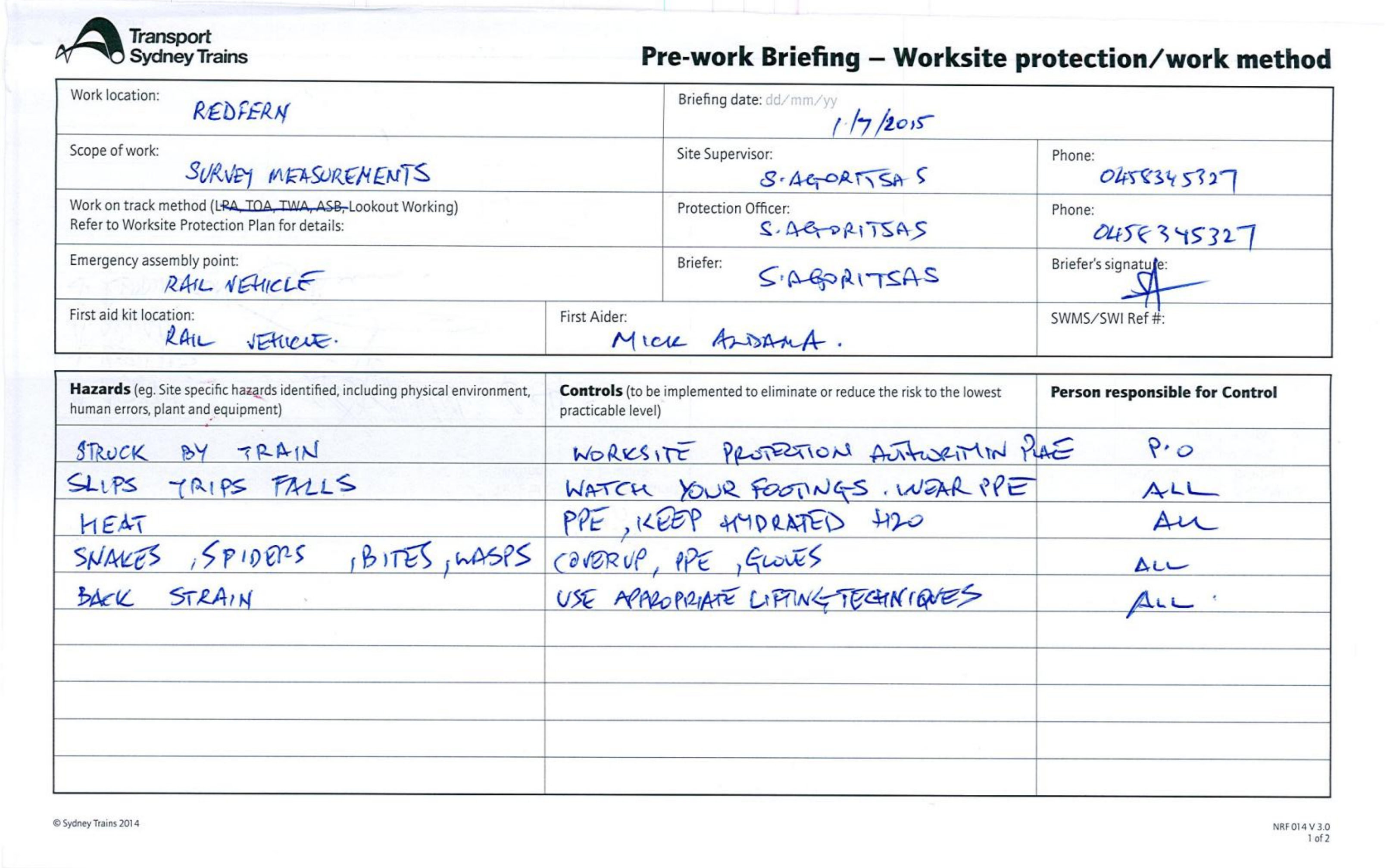

Transport
Sydney Trains

Pre-work Briefing – Worksite protection/work method

Work location: REDFERN	Briefing date: dd/mm/yy 1.7/2015	
Scope of work: SURVEY MEASUREMENTS	Site Supervisor: S.AGORITSAS	Phone: 0458345327
Work on track method (~~LRA, TOA, TWA, ASB,~~ Lookout Working) Refer to Worksite Protection Plan for details:	Protection Officer: S.AGORITSAS	Phone: 0458345327
Emergency assembly point: RAIL VEHICLE	Briefer: S.AGORITSAS	Briefer's signature:
First aid kit location: RAIL VEHICLE.	First Aider: MICK ANDAMA.	SWMS/SWI Ref #:

Hazards (eg. Site specific hazards identified, including physical environment, human errors, plant and equipment)	**Controls** (to be implemented to eliminate or reduce the risk to the lowest practicable level)	**Person responsible for Control**
STRUCK BY TRAIN	WORKSITE PROTECTION AUTHORITY IN PLACE	P.O
SLIPS TRIPS FALLS	WATCH YOUR FOOTINGS. WEAR PPE	ALL
HEAT	PPE, KEEP HYDRATED H2O	ALL
SNAKES, SPIDERS, BITES, WASPS	COVERUP, PPE, GLOVES	ALL
BACK STRAIN	USE APPROPRIATE LIFTING TECHNIQUES	ALL.

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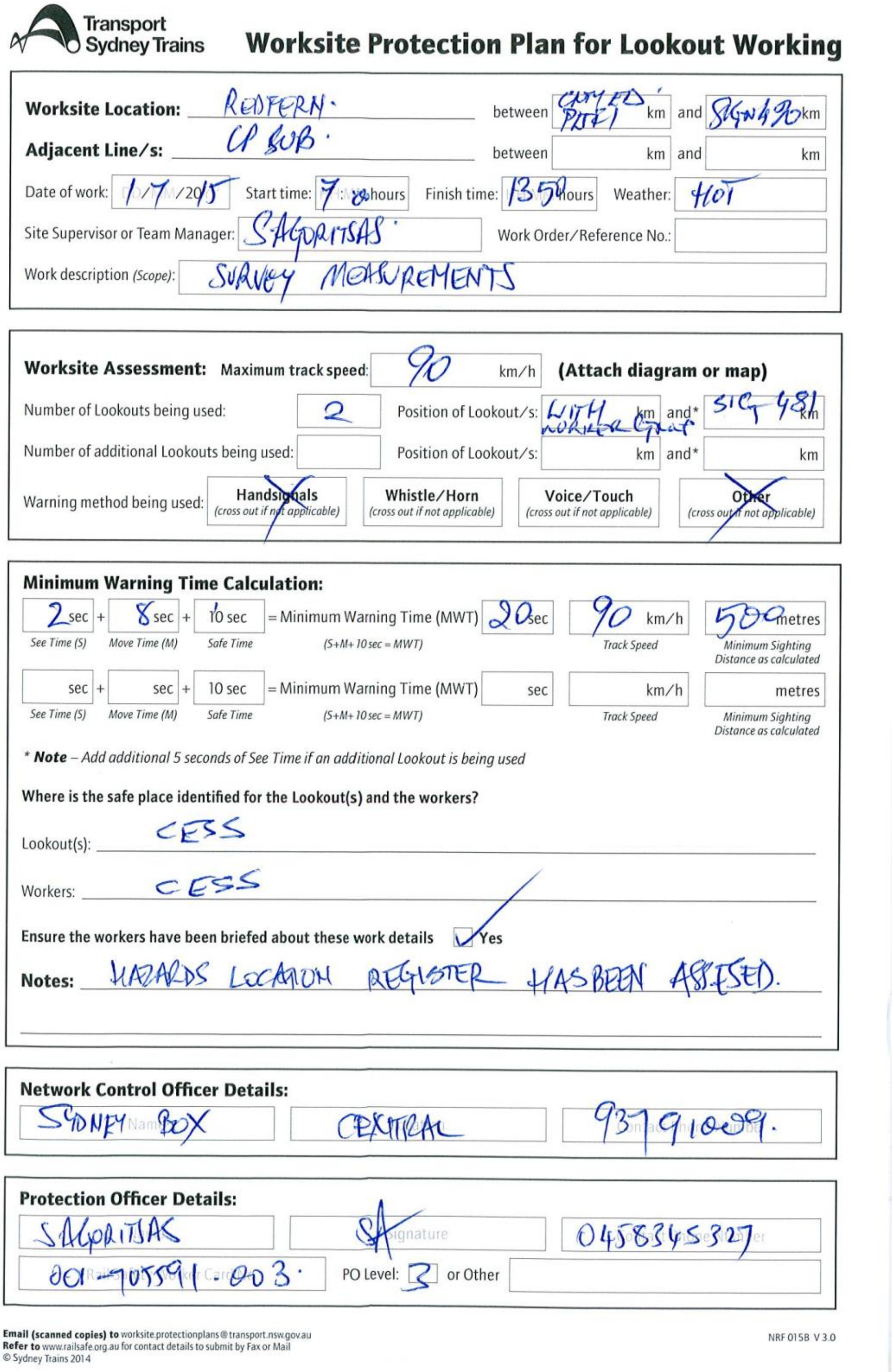
1 of 2



Transport
Sydney Trains

Worksite Protection Plan for Lookout Working

Worksite Location: REDFERN. between CAMPED' PLT 1 km and SIGN 490 km

Adjacent Line/s: CP SUB. between km and km

Date of work: 1/7/2015 Start time: 7:00 hours Finish time: 1350 hours Weather: HOT

Site Supervisor or Team Manager: S AGORITSAS. Work Order/Reference No.:

Work description *(Scope)*: SURVEY MEASUREMENTS

Worksite Assessment: Maximum track speed: 90 km/h **(Attach diagram or map)**

Number of Lookouts being used: 2 Position of Lookout/s: WITH worker group km and* SIG 481 km

Number of additional Lookouts being used: Position of Lookout/s: km and* km

Warning method being used: ~~Handsignals~~ *(cross out if not applicable)* Whistle/Horn *(cross out if not applicable)* Voice/Touch *(cross out if not applicable)* ~~Other~~ *(cross out if not applicable)*

Minimum Warning Time Calculation:

2 sec +	8 sec +	10 sec	= Minimum Warning Time (MWT)	20 sec	90 km/h	500 metres
See Time (S)	*Move Time (M)*	*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*
sec +	sec +	10 sec	= Minimum Warning Time (MWT)	sec	km/h	metres
See Time (S)	*Move Time (M)*	*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*

* **Note** – *Add additional 5 seconds of See Time if an additional Lookout is being used*

Where is the safe place identified for the Lookout(s) and the workers?

Lookout(s): CESS

Workers: CESS

Ensure the workers have been briefed about these work details ☑ **Yes**

Notes: HAZARDS LOCATION REGISTER HAS BEEN ASSESSED.

Network Control Officer Details:

SYDNEY BOX | CENTRAL | 93791009.

Protection Officer Details:

SAGORITSAS | SA | 0458345327

001-905591-003. PO Level: 3 or Other

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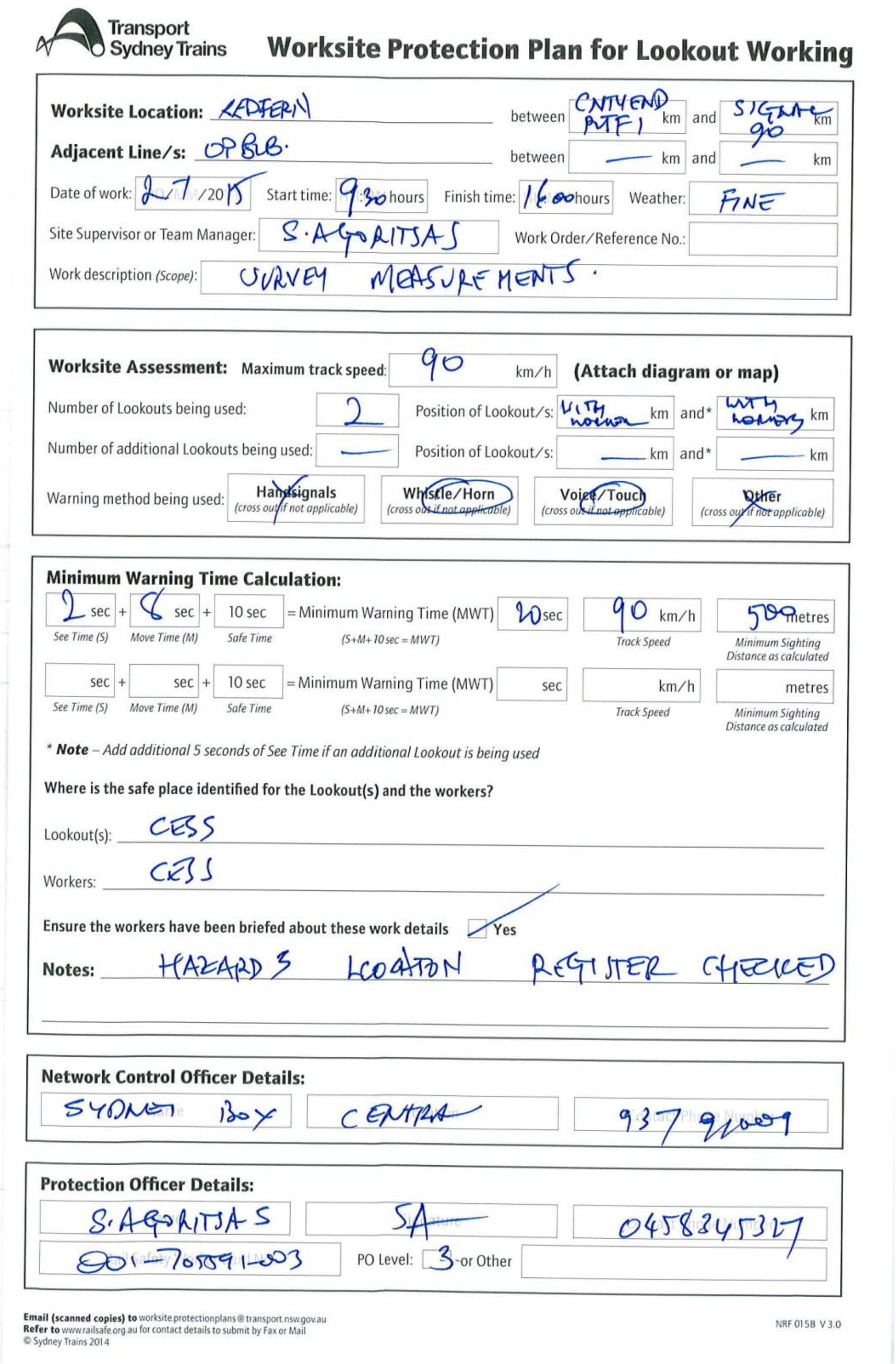

Transport Sydney Trains

Worksite Protection Plan for Lookout Working

Worksite Location: REDFERN between CNTYEND PTF1 km and SIGNAL 90 km

Adjacent Line/s: UP BLB. between — km and — km

Date of work: 2 7 /2015 Start time: 9:30 hours Finish time: 16:00 hours Weather: FINE

Site Supervisor or Team Manager: S. AGORITSAS Work Order/Reference No.:

Work description *(Scope)*: SURVEY MEASUREMENTS.

Worksite Assessment: Maximum track speed: 90 km/h **(Attach diagram or map)**

Number of Lookouts being used: 2 Position of Lookout/s: WITH WORKER km and* WITH WORKER km

Number of additional Lookouts being used: — Position of Lookout/s: — km and* — km

Warning method being used: ~~Handsignals~~ *(cross out if not applicable)* [✓ Whistle/Horn] *(cross out if not applicable)* [✓ Voice/Touch] *(cross out if not applicable)* ~~Other~~ *(cross out if not applicable)*

Minimum Warning Time Calculation:

2 sec +	8 sec +	10 sec	= Minimum Warning Time (MWT)	20 sec	90 km/h	500 metres
See Time (S)	*Move Time (M)*	*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*
sec +	sec +	10 sec	= Minimum Warning Time (MWT)	sec	km/h	metres
See Time (S)	*Move Time (M)*	*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*

* **Note** – *Add additional 5 seconds of See Time if an additional Lookout is being used*

Where is the safe place identified for the Lookout(s) and the workers?

Lookout(s): CESS

Workers: CESS

Ensure the workers have been briefed about these work details ☑ Yes

Notes: HAZARDS LOCATION REGISTER CHECKED

Network Control Officer Details:

SYDNEY BOX | CENTRAL | 937 91009

Protection Officer Details:

S. AGORITSAS | SA | 0458845327

001-70591-003 PO Level: 3 or Other

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Refer to www.railsafe.org.au for contact details to submit by Fax or Mail

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Transport
Sydney Trains

Pre-work Briefing – Worksite protection/work method

Work location: REDFERN

Briefing date: dd/mm/yy 2/7/2015

Scope of work: SURVEY MEASUREMENTS.

Site Supervisor: S.AGORITOS.

Phone: 0458 345 327

Work on track method (~~LPA, TOA, TWA, ASB,~~ [✓ Lookout Working]) ✓
Refer to Worksite Protection Plan for details:

Protection Officer: S.AGORITOS

Phone: 0458 945327

Emergency assembly point: RAIL VEHICLE

Briefer: S.AGORITSAS.

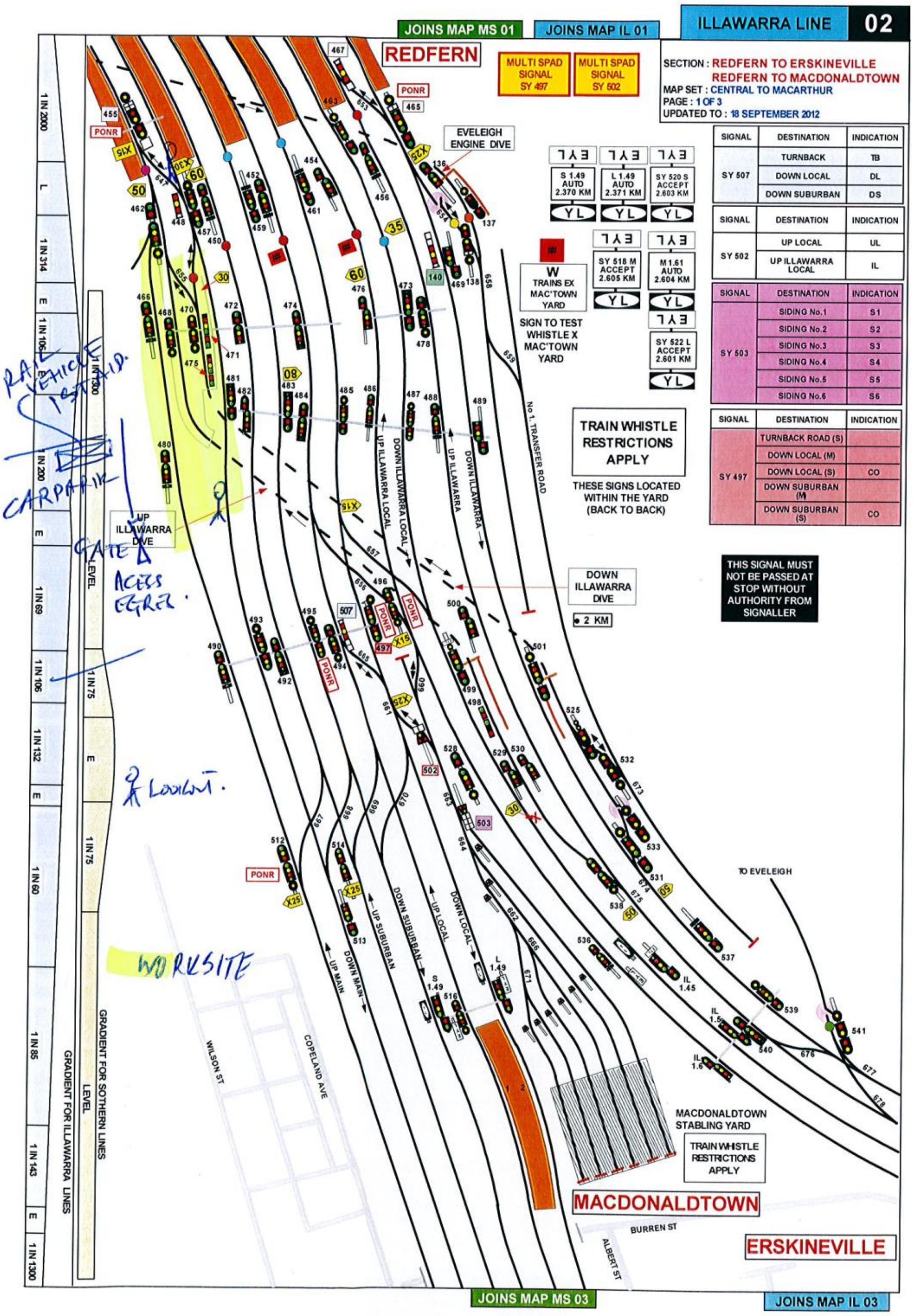
Briefer's signature: SA

First aid kit location: RAIL VEHICLE.

First Aider: MICK ALDAMA

SWMS/SWI Ref #:

Hazards (eg. Site specific hazards identified, including physical environment, human errors, plant and equipment)	**Controls** (to be implemented to eliminate or reduce the risk to the lowest practicable level)	**Person responsible for Control**
STRUCK BY TRAIN	LOOKOUT WORKING SITE PROTECTION	P.O
SLIPS TRIPS FALL	PPE, TREAD CAREFULLY	ALL
HEAT	PPE KEEP HYDRATED H2O	ALL
INSECT BITES	COVER UP PPE GLOVES	ALL



ILLAWARRA LINE 02

SECTION : REDFERN TO ERSKINEVILLE
REDFERN TO MACDONALDTOWN
MAP SET : CENTRAL TO MACARTHUR
PAGE : 1 OF 3
UPDATED TO : 18 SEPTEMBER 2012

SIGNAL	DESTINATION	INDICATION
SY 507	TURNBACK	TB
	DOWN LOCAL	DL
	DOWN SUBURBAN	DS

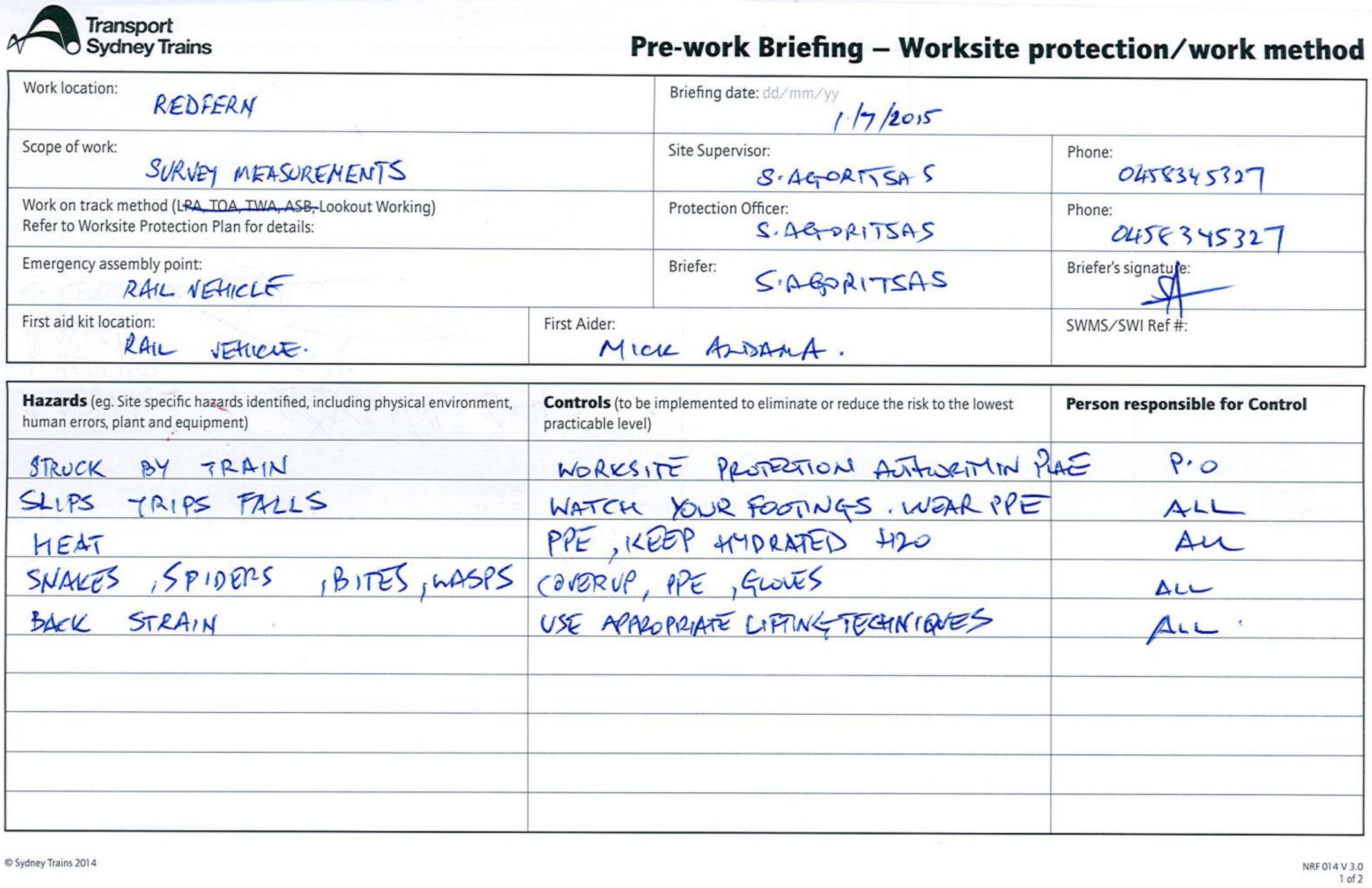
SIGNAL	DESTINATION	INDICATION
SY 502	UP LOCAL	UL
	UP ILLAWARRA LOCAL	IL

SIGNAL	DESTINATION	INDICATION
SY 503	SIDING No.1	S1
	SIDING No.2	S2
	SIDING No.3	S3
	SIDING No.4	S4
	SIDING No.5	S5
	SIDING No.6	S6

SIGNAL	DESTINATION	INDICATION
SY 497	TURNBACK ROAD (S)	
	DOWN LOCAL (M)	
	DOWN LOCAL (S)	CO
	DOWN SUBURBAN (M)	
	DOWN SUBURBAN (S)	CO

For train crew only - not for any safety related use

MAIN MENU
ILLAWARRA STATION MENU



Transport
Sydney Trains

Pre-work Briefing – Worksite protection/work method

Work location: REDFERN	Briefing date: dd/mm/yy 1/7/2015	
Scope of work: SURVEY MEASUREMENTS	Site Supervisor: S·AGORITSAS	Phone: 0458345327
Work on track method (~~LRA, TOA, TWA, ASB,~~ Lookout Working) Refer to Worksite Protection Plan for details:	Protection Officer: S·AGORITSAS	Phone: 0458345327
Emergency assembly point: RAIL VEHICLE	Briefer: S·AGORITSAS	Briefer's signature:
First aid kit location: RAIL VEHICLE.	First Aider: MICK ALDAMA.	SWMS/SWI Ref #:

Hazards (eg. Site specific hazards identified, including physical environment, human errors, plant and equipment)	**Controls** (to be implemented to eliminate or reduce the risk to the lowest practicable level)	**Person responsible for Control**
STRUCK BY TRAIN	WORKSITE PROTECTION AUTHORITY IN PLACE	P.O
SLIPS TRIPS FALLS	WATCH YOUR FOOTINGS. WEAR PPE	ALL
HEAT	PPE, KEEP HYDRATED H2O	ALL
SNAKES, SPIDERS, BITES, WASPS	COVERUP, PPE, GLOVES	ALL
BACK STRAIN	USE APPROPRIATE LIFTING TECHNIQUES	ALL.

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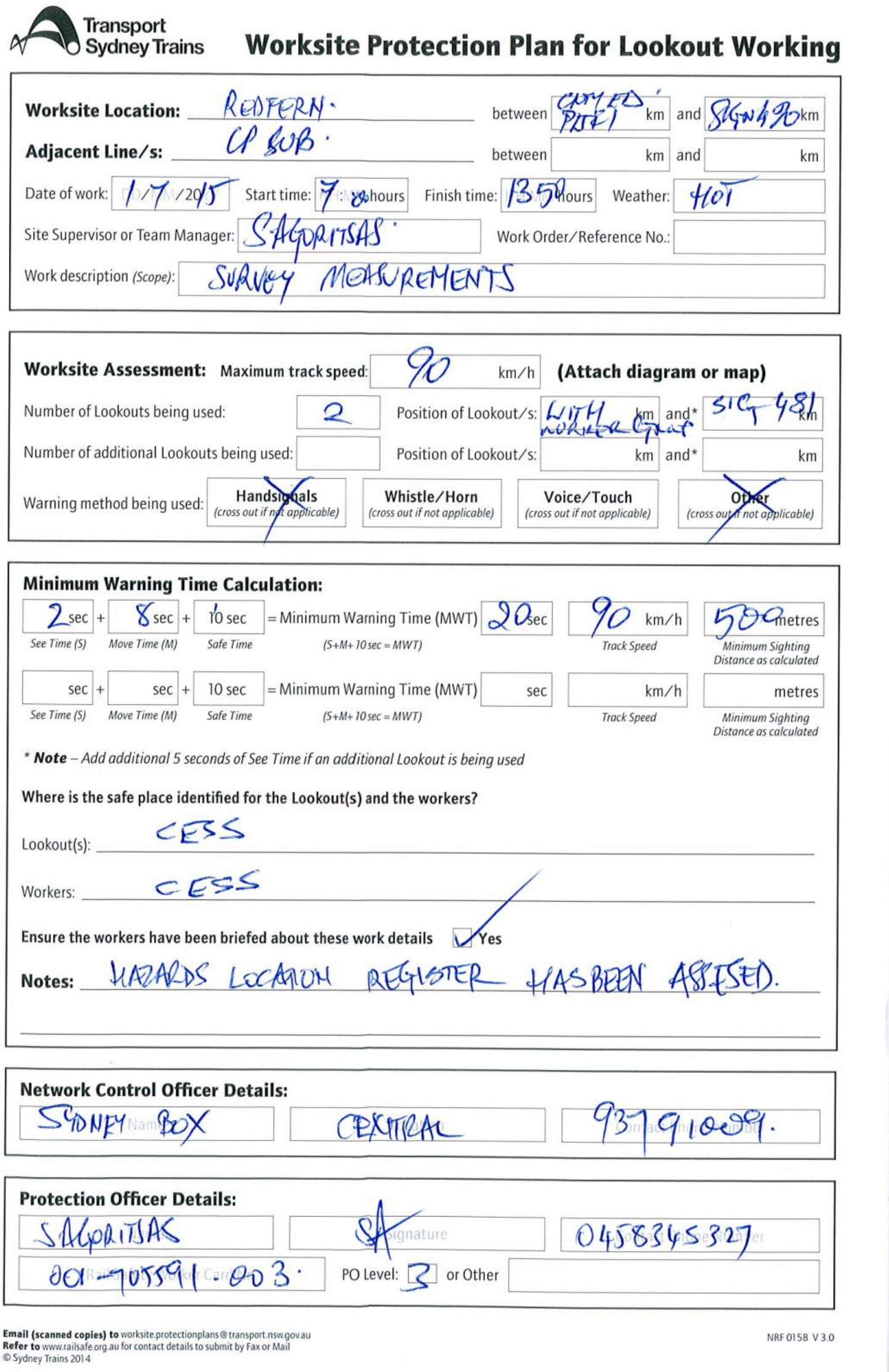
1 of 2



Transport
Sydney Trains

Worksite Protection Plan for Lookout Working

Worksite Location: REDFERN. between CAMFED' PLTF1 km and SIGN490 km

Adjacent Line/s: CP SUB. between km and km

Date of work: 1/7/2015 Start time: 7:00 hours Finish time: 1350 hours Weather: HOT

Site Supervisor or Team Manager: S.AGORITSAS. Work Order/Reference No.:

Work description *(Scope)*: SURVEY MEASUREMENTS

Worksite Assessment: **Maximum track speed:** 90 km/h **(Attach diagram or map)**

Number of Lookouts being used: 2 Position of Lookout/s: WITH WORKER GROUP km and* SIG 481 km

Number of additional Lookouts being used: Position of Lookout/s: km and* km

Warning method being used: **~~Handsignals~~** *~~(cross out if not applicable)~~* **Whistle/Horn** *(cross out if not applicable)* **Voice/Touch** *(cross out if not applicable)* **~~Other~~** *~~(cross out if not applicable)~~*

Minimum Warning Time Calculation:

2 sec + 8 sec + 10 sec = Minimum Warning Time (MWT) 20 sec 90 km/h 500 metres

See Time (S) *Move Time (M)* *Safe Time* *(S+M+ 10 sec = MWT)* *Track Speed* *Minimum Sighting Distance as calculated*

sec + sec + 10 sec = Minimum Warning Time (MWT) sec km/h metres

See Time (S) *Move Time (M)* *Safe Time* *(S+M+ 10 sec = MWT)* *Track Speed* *Minimum Sighting Distance as calculated*

* ***Note*** *– Add additional 5 seconds of See Time if an additional Lookout is being used*

Where is the safe place identified for the Lookout(s) and the workers?

Lookout(s): CESS

Workers: CESS

Ensure the workers have been briefed about these work details ☑ **Yes**

Notes: HAZARDS LOCATION REGISTER HAS BEEN ASSESSED.

Network Control Officer Details:

SYDNEY BOX | CENTRAL | 93791009.

Protection Officer Details:

SAGORITSAS | SA | 0458345327

001-905591-003. PO Level: 3 or Other

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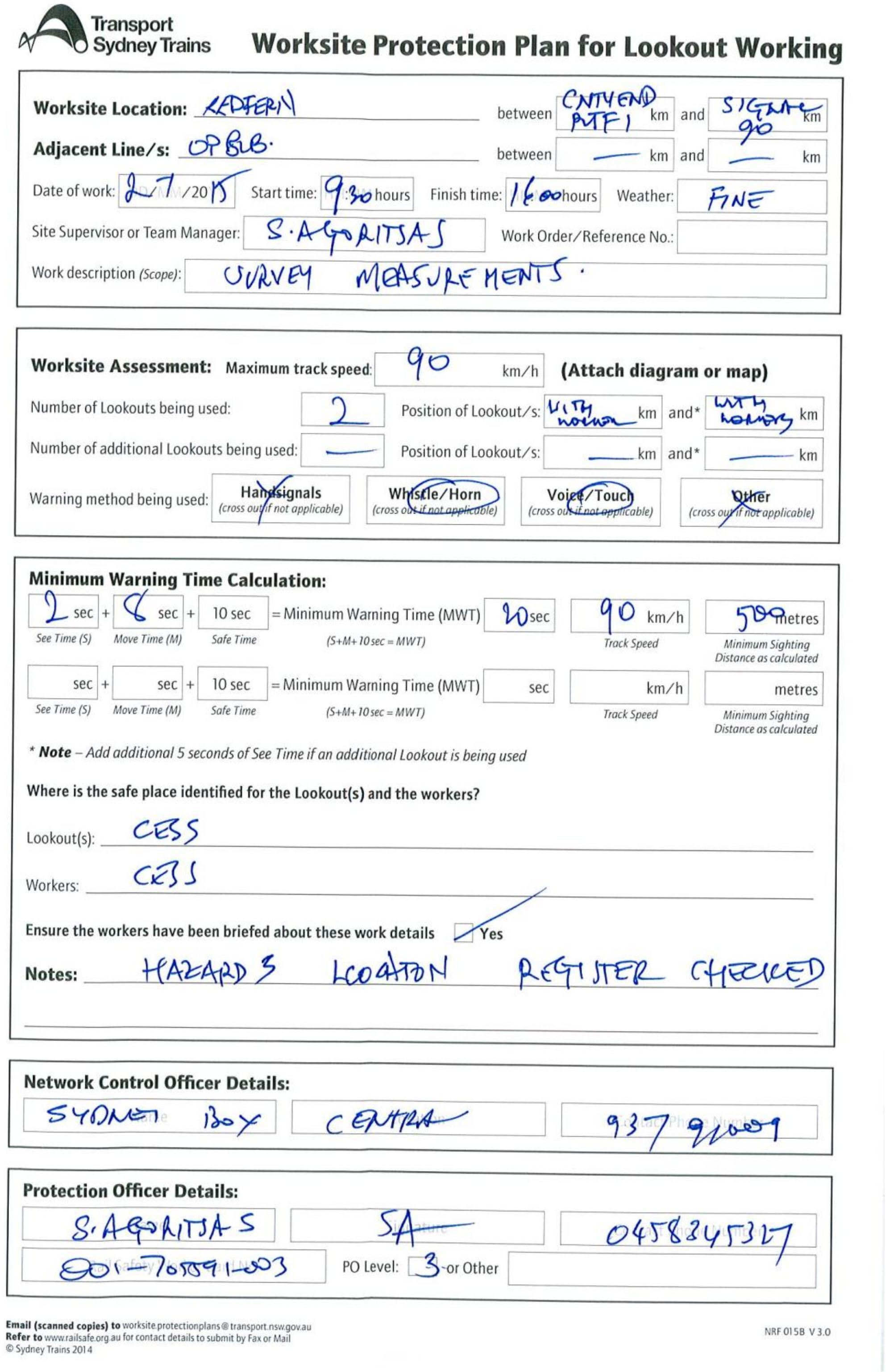

Transport
Sydney Trains

Worksite Protection Plan for Lookout Working

Worksite Location: REDFERN between CNTY END PTF 1 km and SIGNAL 90 km

Adjacent Line/s: UP BLB. between — km and — km

Date of work: 2/7/2015 Start time: 9:30 hours Finish time: 16:00 hours Weather: FINE

Site Supervisor or Team Manager: S.AGORITSAS Work Order/Reference No.:

Work description *(Scope)*: SURVEY MEASUREMENTS.

Worksite Assessment: **Maximum track speed:** 90 km/h **(Attach diagram or map)**

Number of Lookouts being used: 2 Position of Lookout/s: WITH WORKER km and* WITH WORKERS km

Number of additional Lookouts being used: — Position of Lookout/s: — km and* — km

Warning method being used: ~~**Handsignals** *(cross out if not applicable)*~~ [✓ **Whistle/Horn** *(cross out if not applicable)*] [✓ **Voice/Touch** *(cross out if not applicable)*] ~~**Other** *(cross out if not applicable)*~~

Minimum Warning Time Calculation:

2 sec	+	8 sec	+	10 sec	= Minimum Warning Time (MWT)	20 sec	90 km/h	500 metres
See Time (S)		*Move Time (M)*		*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*
sec	+	sec	+	10 sec	= Minimum Warning Time (MWT)	sec	km/h	metres
See Time (S)		*Move Time (M)*		*Safe Time*	*(S+M+10 sec = MWT)*		*Track Speed*	*Minimum Sighting Distance as calculated*

* ***Note** – Add additional 5 seconds of See Time if an additional Lookout is being used*

Where is the safe place identified for the Lookout(s) and the workers?

Lookout(s): CESS

Workers: CESS

Ensure the workers have been briefed about these work details ☑ Yes

Notes: HAZARDS LOCATION REGISTER CHECKED

Network Control Officer Details:

SYDNEY BOX	CENTRAL	937 91009

Protection Officer Details:

S.AGORITSAS	SA	0458845327
001-705591-003	PO Level: 3 or Other	

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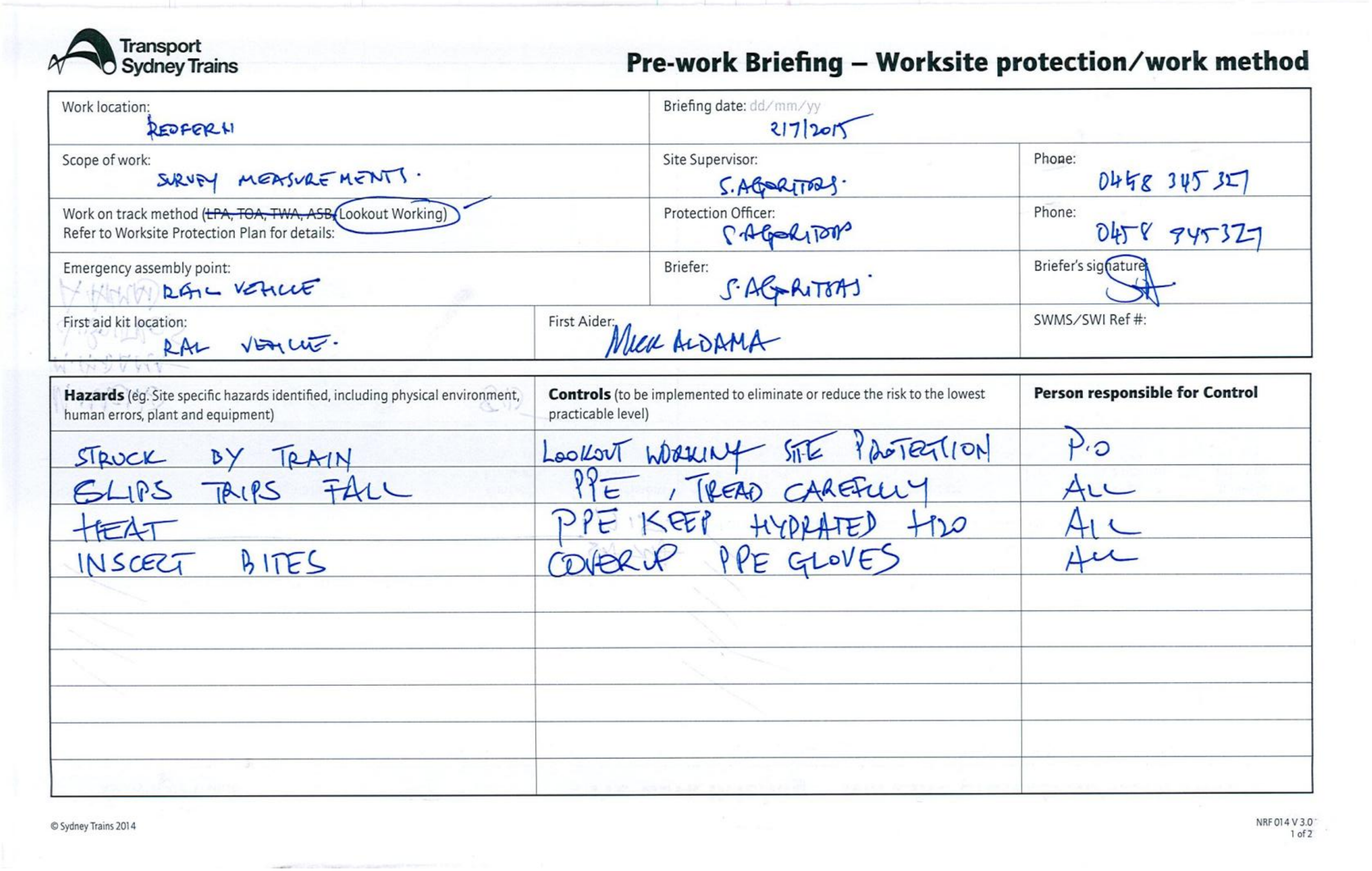

Transport
Sydney Trains

Pre-work Briefing – Worksite protection/work method

Work location: REDFERN	Briefing date: dd/mm/yy 2/7/2015	
Scope of work: SURVEY MEASUREMENTS.	Site Supervisor: S.AGORITSAS.	Phone: 0458 345 327
Work on track method (~~LPA, TOA, TWA, ASB,~~ [✓ Lookout Working]) Refer to Worksite Protection Plan for details:	Protection Officer: S.AGORITSAS	Phone: 0458 945327
Emergency assembly point: RAIL VEHICLE	Briefer: S.AGORITSAS.	Briefer's signature:
First aid kit location: RAIL VEHICLE.	First Aider: MICK ALDAMA	SWMS/SWI Ref #:

Hazards (eg. Site specific hazards identified, including physical environment, human errors, plant and equipment)	**Controls** (to be implemented to eliminate or reduce the risk to the lowest practicable level)	**Person responsible for Control**
STRUCK BY TRAIN	LOOKOUT WORKING SITE PROTECTION	P.O
SLIPS TRIPS FALL	PPE, TREAD CAREFULLY	ALL
HEAT	PPE KEEP HYDRATED H2O	ALL
INSECT BITES	COVER UP PPE GLOVES	ALL

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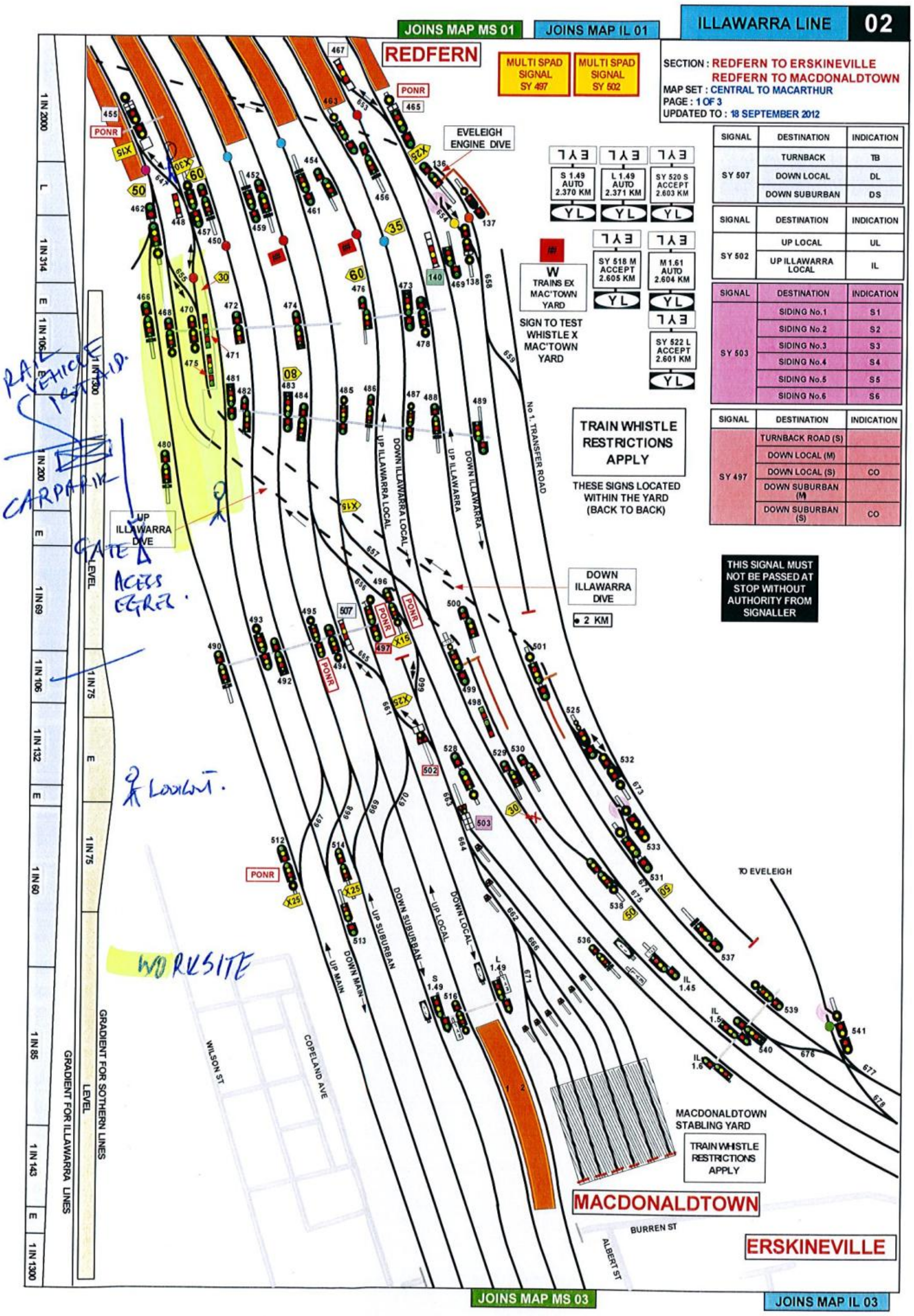
NRF 014 V 3.0
1 of 2



ILLAWARRA LINE **02**

SECTION : REDFERN TO ERSKINEVILLE
REDFERN TO MACDONALDTOWN
MAP SET : CENTRAL TO MACARTHUR
PAGE : 1 OF 3
UPDATED TO : 18 SEPTEMBER 2012

SIGNAL	DESTINATION	INDICATION
SY 507	TURNBACK	TB
	DOWN LOCAL	DL
	DOWN SUBURBAN	DS

SIGNAL	DESTINATION	INDICATION
SY 502	UP LOCAL	UL
	UP ILLAWARRA LOCAL	IL

SIGNAL	DESTINATION	INDICATION
SY 503	SIDING No.1	S1
	SIDING No.2	S2
	SIDING No.3	S3
	SIDING No.4	S4
	SIDING No.5	S5
	SIDING No.6	S6

SIGNAL	DESTINATION	INDICATION
SY 497	TURNBACK ROAD (S)	
	DOWN LOCAL (M)	
	DOWN LOCAL (S)	CO
	DOWN SUBURBAN (M)	
	DOWN SUBURBAN (S)	CO

THIS SIGNAL MUST NOT BE PASSED AT STOP WITHOUT AUTHORITY FROM SIGNALLER

MULTI SPAD SIGNAL SY 497

MULTI SPAD SIGNAL SY 502

TRAIN WHISTLE RESTRICTIONS APPLY

THESE SIGNS LOCATED WITHIN THE YARD (BACK TO BACK)

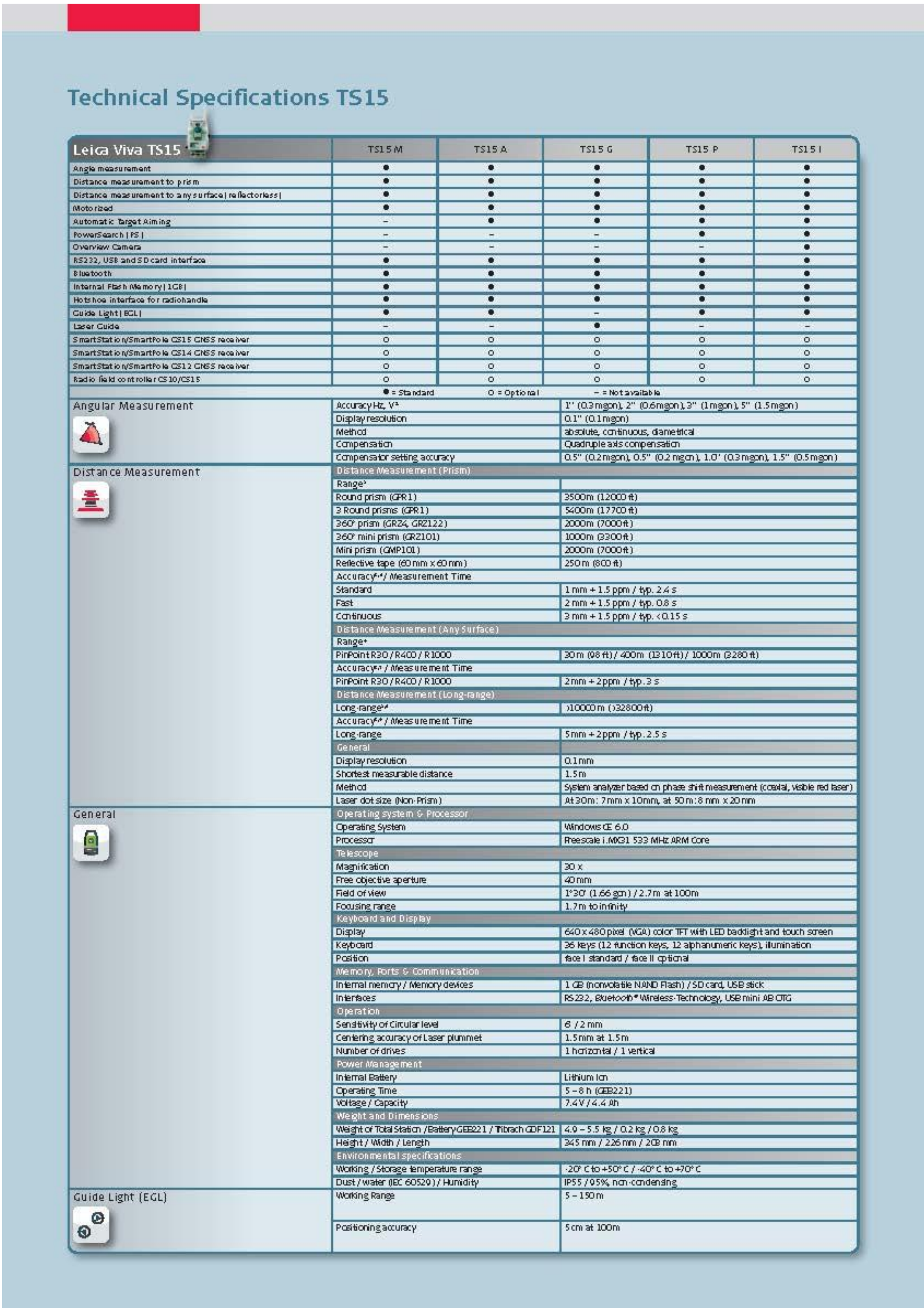
W TRAINS EX MAC'TOWN YARD

SIGN TO TEST WHISTLE X MAC'TOWN YARD

MAIN MENU

ILLAWARRA STATION MENU

Appendix C. Leica TS15 & TS30 Specifications

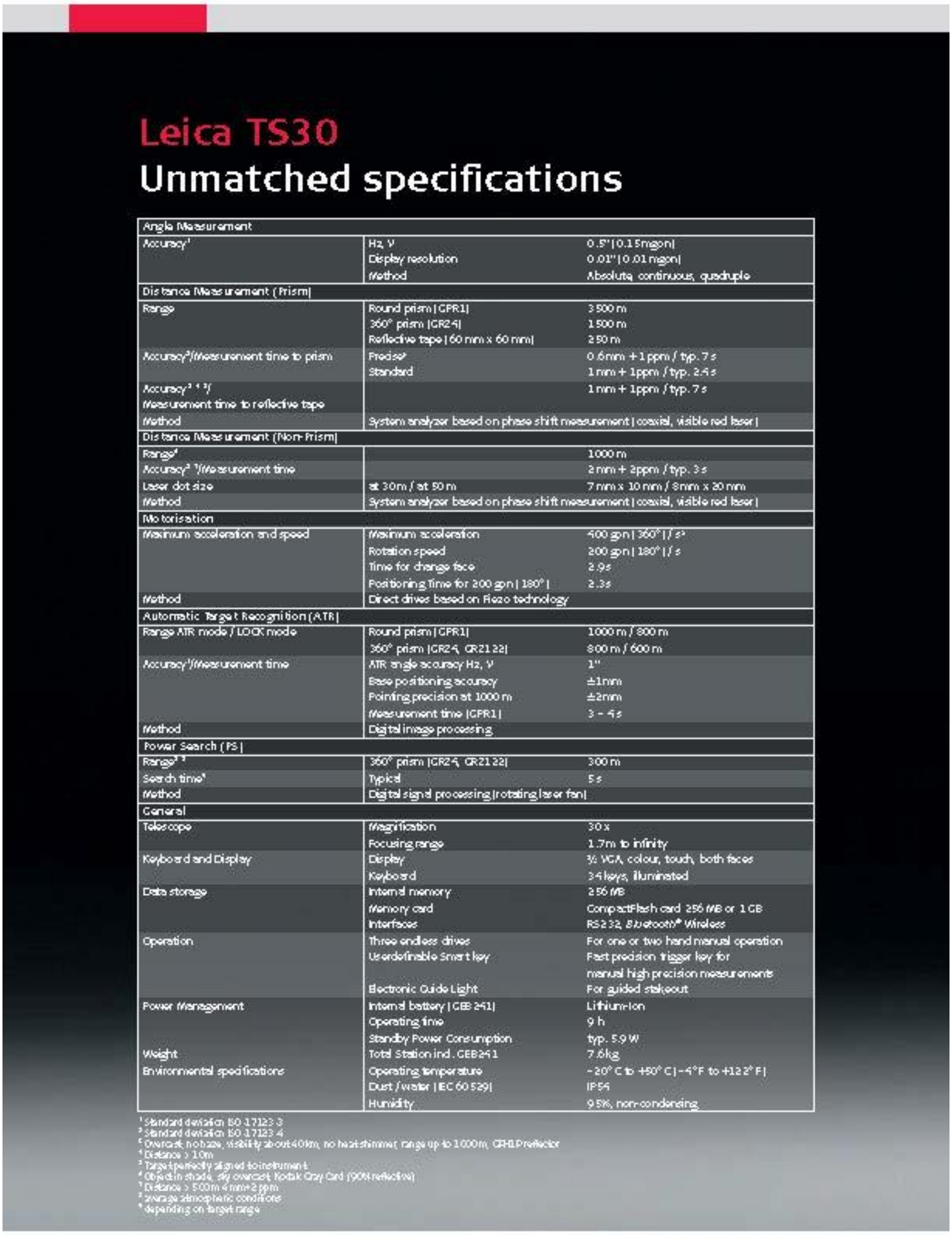


Technical Specifications TS15

Leica Viva TS15	TS15 M	TS15 A	TS15 G	TS15 P	TS15 I
Angle measurement	●	●	●	●	●
Distance measurement to prism	●	●	●	●	●
Distance measurement to any surface (reflectorless)	●	●	●	●	●
Motorized	●	●	●	●	●
Automatic Target Aiming	–	●	●	●	●
PowerSearch (PS)	–	–	–	●	●
Overview Camera	–	–	–	–	●
RS232, USB and SD card interface	●	●	●	●	●
Bluetooth	●	●	●	●	●
Internal Flash Memory (1GB)	●	●	●	●	●
Hotshoe interface for radiohandle	●	●	●	●	●
Guide Light (EGL)	●	●	–	●	●
Laser Guide	–	–	●	–	–
SmartStation/SmartPole GS15 GNSS receiver	○	○	○	○	○
SmartStation/SmartPole GS14 GNSS receiver	○	○	○	○	○
SmartStation/SmartPole GS12 GNSS receiver	○	○	○	○	○
Radio field controller CS10/CS15	○	○	○	○	○

● = Standard ○ = Optional – = Not available

Angular Measurement	Accuracy Hz, V[1]	1" (0.3 mgon), 2" (0.6mgon), 3" (1mgon), 5" (1.5mgon)
	Display resolution	0.1" (0.1mgon)
	Method	absolute, continuous, diametrical
	Compensation	Quadruple axis compensation
	Compensator setting accuracy	0.5" (0.2mgon), 0.5" (0.2 mgon), 1.0" (0.3mgon), 1.5" (0.5mgon)
Distance Measurement	Distance Measurement (Prism)	
	Range[2]	
	Round prism (GPR1)	3500m (12000 ft)
	3 Round prisms (GPR1)	5400m (17700 ft)
	360° prism (GRZ4, GRZ122)	2000m (7000 ft)
	360° mini prism (GRZ101)	1000m (3300 ft)
	Mini prism (GMP101)	2000m (7000 ft)
	Reflective tape (60 mm x 60 mm)	250 m (800 ft)
	Accuracy[3,4] / Measurement Time	
	Standard	1 mm + 1.5 ppm / typ. 2.4 s
	Fast	2 mm + 1.5 ppm / typ. 0.8 s
	Continuous	3 mm + 1.5 ppm / typ. < 0.15 s
	Distance Measurement (Any Surface)	
	Range[4]	
	PinPoint R30 / R400 / R1000	30 m (98 ft) / 400m (1310 ft) / 1000m (3280 ft)
	Accuracy[3,4] / Measurement Time	
	PinPoint R30 / R400 / R1000	2 mm + 2 ppm / typ. 3 s
	Distance Measurement (Long-range)	
	Long-range[2,4]	>10000 m (>32800 ft)
	Accuracy[3,4] / Measurement Time	
	Long-range	5 mm + 2 ppm / typ. 2.5 s
	General	
	Display resolution	0.1 mm
	Shortest measurable distance	1.5 m
	Method	System analyzer based on phase shift measurement (coaxial, visible red laser)
	Laser dot size (Non-Prism)	At 30m: 7 mm x 10mm, at 50 m: 8 mm x 20 mm
General	Operating system & Processor	
	Operating System	Windows CE 6.0
	Processor	Freescale i.MX31 533 MHz ARM Core
	Telescope	
	Magnification	30 x
	Free objective aperture	40 mm
	Field of view	1°30' (1.66 gon) / 2.7 m at 100m
	Focusing range	1.7 m to infinity
	Keyboard and Display	
	Display	640 x 480 pixel (VGA) color TFT with LED backlight and touch screen
	Keyboard	36 keys (12 function keys, 12 alphanumeric keys), illumination
	Position	face I standard / face II optional
	Memory, Ports & Communication	
	Internal memory / Memory devices	1 GB (nonvolatile NAND Flash) / SD card, USB stick
	Interfaces	RS232, Bluetooth® Wireless-Technology, USB mini AB OTG
	Operation	
	Sensitivity of Circular level	6' / 2 mm
	Centering accuracy of Laser plummet	1.5 mm at 1.5 m
	Number of drives	1 horizontal / 1 vertical
	Power Management	
	Internal Battery	Lithium Ion
	Operating Time	5 – 8 h (GEB221)
	Voltage / Capacity	7.4 V / 4.4 Ah
	Weight and Dimensions	
	Weight of Total Station / Battery GEB221 / Tribrach GDF121	4.9 – 5.5 kg / 0.2 kg / 0.8 kg
	Height / Width / Length	345 mm / 226 mm / 203 mm
	Environmental specifications	
	Working / Storage temperature range	-20° C to +50° C / -40° C to +70° C
	Dust / water (IEC 60529) / Humidity	IP55 / 95%, non-condensing
Guide Light (EGL)	Working Range	5 – 150 m
	Positioning accuracy	5 cm at 100m



Leica TS30
Unmatched specifications

Angle Measurement		
Accuracy[1]	Hz, V	0.5" | 0.15 mgon |
	Display resolution	0.01" | 0.01 mgon |
	Method	Absolute, continuous, quadruple
Distance Measurement (Prism)		
Range	Round prism | GPR1 |	3500 m
	360° prism | GRZ4 |	1500 m
	Reflective tape | 60 mm x 60 mm |	250 m
Accuracy[2]/Measurement time to prism	Precise[3]	0.6mm + 1 ppm / typ. 7 s
	Standard	1 mm + 1ppm / typ. 2.4 s
Accuracy[2, 4, 5]/ Measurement time to reflective tape		1 mm + 1ppm / typ. 7 s
Method	System analyzer based on phase shift measurement | coaxial, visible red laser |	
Distance Measurement (Non-Prism)		
Range[6]		1000 m
Accuracy[2, 7]/Measurement time		2 mm + 2ppm / typ. 3 s
Laser dot size	at 30 m / at 50 m	7 mm x 10 mm / 8 mm x 20 mm
Method	System analyzer based on phase shift measurement | coaxial, visible red laser |	
Motorisation		
Maximum acceleration and speed	Maximum acceleration	400 gon | 360° | / s²
	Rotation speed	200 gon | 180° | / s
	Time for change face	2.9 s
	Positioning Time for 200 gon | 180° |	2.3 s
Method	Direct drives based on Piezo technology	
Automatic Target Recognition (ATR)		
Range ATR mode / LOCK mode	Round prism | GPR1 |	1000 m / 800 m
	360° prism | GRZ4, GRZ122 |	800 m / 600 m
Accuracy[1]/Measurement time	ATR angle accuracy Hz, V	1"
	Base positioning accuracy	±1mm
	Pointing precision at 1000 m	±2mm
	Measurement time | GPR1 |	3 – 4 s
Method	Digital image processing	
Power Search (PS)		
Range[3, 8]	360° prism | GRZ4, GRZ122 |	300 m
Search time[9]	Typical	5 s
Method	Digital signal processing | rotating laser fan |	
General		
Telescope	Magnification	30 x
	Focusing range	1.7 m to infinity
Keyboard and Display	Display	¼ VGA, colour, touch, both faces
	Keyboard	34 keys, illuminated
Data storage	Internal memory	256 MB
	Memory card	CompactFlash card 256 MB or 1 GB
	Interfaces	RS232, *Bluetooth*® Wireless
Operation	Three endless drives	For one or two hand manual operation
	Userdefinable Smart key	Fast precision trigger key for manual high precision measurements
	Electronic Guide Light	For guided stakeout
Power Management	Internal battery | GEB 241 |	Lithium-Ion
	Operating time	9 h
	Standby Power Consumption	typ. 5.9 W
Weight	Total Station incl. GEB241	7.6 kg
Environmental specifications	Operating temperature	–20° C to +50° C | –4°F to +122° F |
	Dust / water | IEC 60529 |	IP54
	Humidity	95%, non-condensing

[1] Standard deviation ISO 17123-3
[2] Standard deviation ISO 17123-4
[3] Overcast, no haze, visibility about 40 km, no heat shimmer, range up to 1000 m, GPH1P reflector
[4] Distance > 10 m
[5] Target perfectly aligned to instrument
[6] Object in shade, sky overcast, Kodak Gray Card (90% reflective)
[7] Distance > 500 m 4 mm+2 ppm
[8] average atmospheric conditions
[9] depending on target range

Appendix D Leica MS50 Specifications

Leica Nova MS50 MultiStation

ANGLE MEASUREMENT		
Accuracy[1] Hz and V	Absolute, continuous, quadruple	1" (0.3 mgon)
DISTANCE MEASUREMENT		
Range[2]	Prism (GPR1, GPH1P)[3] Non-Prism / Any surface[4]	1.5 m to >10000 m 1.5 m to 2000 m
Accuracy / Measurement time	Single (prism)[2,5] Single (Any surface)[2,4,5,6]	1 mm + 1.5 ppm / typ. 1.5 s 2 mm + 2 ppm / typ. 1.5 s
Laser dot size	at 50 m	8 mm x 20 mm
Measurement technology	Wave Form Digitising	coaxial, visible red laser
SCANNING		
Max. Range[7] / Range noise (1 sigma)[4]	1000 Hz mode 250 Hz mode 62 Hz mode 1 Hz mode	300 m / 1.0 mm at 50 m 400 m / 0.8 mm at 50 m 500 m / 0.6 mm at 50 m 1000 m / 0.6 mm at 50 m
Visualisation of point cloud	Onboard 3D point cloud viewer, including true colour point clouds	
IMAGING		
Overview and telescope camera	Sensor Field of view (overview / telescope) Frame rate	5 Mpixel CMOS sensor 19.4° / 1.5° Up to 20 frames per second
MOTORISATION		
Direct drives based on Piezo technology	Rotation speed / Time to Change Face	max. 200 gon (180°) per s / typ. 2.9 s
AUTOMATIC AIMING (ATR)		
Range ATR mode[2] / Lock mode[2]	Circular prism (GPR1, GPH1P) 360° prism (GRZ4, GRZ122)	1000 m / 800 m 800 m / 600 m
Accuracy[1,2] / Measurement time	ATR angle accuracy Hz, V	1" (0.3 mgon) / typ. 2.5 s
POWERSEARCH		
Range / Search time[8]	360° prism (GRZ4, GRZ122)	300 m / typ. 5 s
GUIDE LIGHT (EGL)		
Working Range / Accuracy		5–150 m / typ. 5 cm @ 100 m
GENERAL		
Autofocus telescope	Magnification / Focus Range	30 x / 1.7 m to infinity
Display and Keyboard	VGA, colour, touch, both faces	36 keys, illumination
Operation	3x endless drives, 1x Servofocus drive, 2x Autofocus keys, User-definable SmartKey	
Power management	Exchangeable Lithium-Ion battery with internal charging capability	Operating Time 7–9 h
Data storage	Internal memory / Memory card	1 GB / SD card 1 GB or 8 GB
Interfaces	RS232, USB, Bluetooth®, WLAN	
Weight	MultiStation incl. battery	7.6 kg
Environmental specifications	Working temperature range Dust & Water (IEC 60529) / Blowing rain Humidity	–20°C to +50°C IP65 / MIL-STD-810G, Method 506.5-I 95%, non-condensing

[1] Standard deviation ISO 17123-3
[2] Overcast, no haze, visibility about 40 km, no heat shimmer
[3] 1.5 m to 3000 m for 360° prisms (GRZ4, GRZ122)
[4] Object in shade, sky overcast, Kodak Gray Card (90% reflective)
[5] Standard deviation ISO 17123-4
[6] Distance > 500 m: Accuracy 4 mm + 2 ppm, Measurement Time typ. 4 s
[7] Object in shade, sky overcast, uninterrupted visibility, static target object, Kodak Gray Card (90% reflective)
[8] Target perfectly aligned to the instrument

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Leica Geosystems AG
Heerbrugg, Switzerland

www.leica-geosystems.com

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Leica
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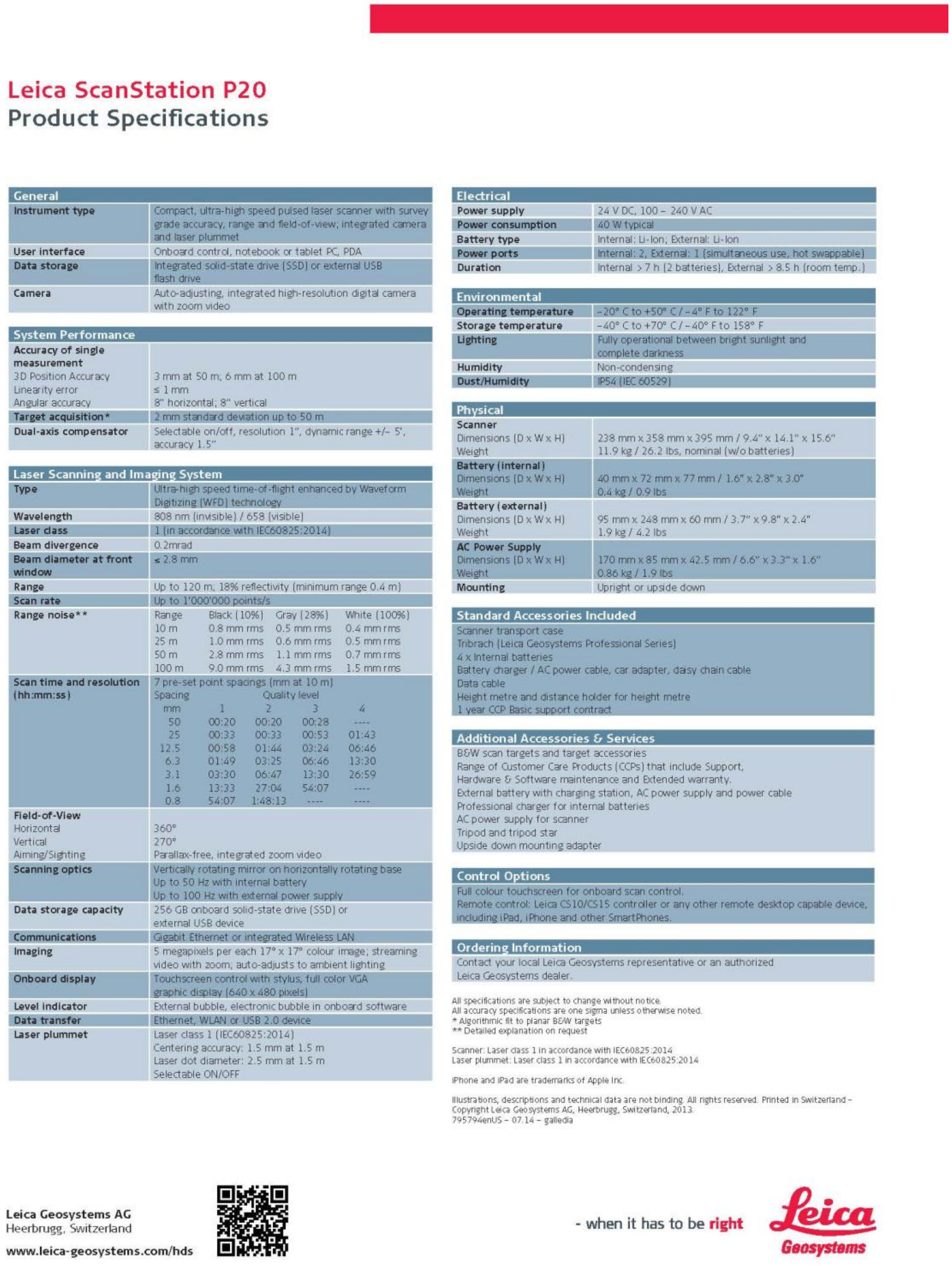
Appendix E. Leica P20 Specifications



Leica ScanStation P20
Product Specifications

General

Instrument type	Compact, ultra-high speed pulsed laser scanner with survey grade accuracy, range and field-of-view; integrated camera and laser plummet
User interface	Onboard control, notebook or tablet PC, PDA
Data storage	Integrated solid-state drive (SSD) or external USB flash drive
Camera	Auto-adjusting, integrated high-resolution digital camera with zoom video

System Performance

Accuracy of single measurement	
3D Position Accuracy	3 mm at 50 m; 6 mm at 100 m
Linearity error	≤ 1 mm
Angular accuracy	8" horizontal; 8" vertical
Target acquisition*	2 mm standard deviation up to 50 m
Dual-axis compensator	Selectable on/off, resolution 1", dynamic range +/– 5', accuracy 1.5"

Laser Scanning and Imaging System

Type	Ultra-high speed time-of-flight enhanced by Waveform Digitizing (WFD) technology
Wavelength	808 nm (invisible) / 658 (visible)
Laser class	1 (in accordance with IEC60825:2014)
Beam divergence	0.2mrad
Beam diameter at front window	≤ 2.8 mm
Range	Up to 120 m; 18% reflectivity (minimum range 0.4 m)
Scan rate	Up to 1'000'000 points/s

Range noise**

Range	Black (10%)	Gray (28%)	White (100%)
10 m	0.8 mm rms	0.5 mm rms	0.4 mm rms
25 m	1.0 mm rms	0.6 mm rms	0.5 mm rms
50 m	2.8 mm rms	1.1 mm rms	0.7 mm rms
100 m	9.0 mm rms	4.3 mm rms	1.5 mm rms

Scan time and resolution (hh:mm:ss)

7 pre-set point spacings (mm at 10 m)

Spacing	Quality level			
mm	1	2	3	4
50	00:20	00:20	00:28	----
25	00:33	00:33	00:53	01:43
12.5	00:58	01:44	03:24	06:46
6.3	01:49	03:25	06:46	13:30
3.1	03:30	06:47	13:30	26:59
1.6	13:33	27:04	54:07	----
0.8	54:07	1:48:13	----	----

Field-of-View	
Horizontal	360°
Vertical	270°
Aiming/Sighting	Parallax-free, integrated zoom video
Scanning optics	Vertically rotating mirror on horizontally rotating base Up to 50 Hz with internal battery Up to 100 Hz with external power supply
Data storage capacity	256 GB onboard solid-state drive (SSD) or external USB device
Communications	Gigabit Ethernet or integrated Wireless LAN
Imaging	5 megapixels per each 17° x 17° colour image; streaming video with zoom; auto-adjusts to ambient lighting
Onboard display	Touchscreen control with stylus, full color VGA graphic display (640 x 480 pixels)
Level indicator	External bubble, electronic bubble in onboard software
Data transfer	Ethernet, WLAN or USB 2.0 device
Laser plummet	Laser class 1 (IEC60825:2014) Centering accuracy: 1.5 mm at 1.5 m Laser dot diameter: 2.5 mm at 1.5 m Selectable ON/OFF

Electrical

Power supply	24 V DC, 100 – 240 V AC
Power consumption	40 W typical
Battery type	Internal: Li-Ion; External: Li-Ion
Power ports	Internal: 2, External: 1 (simultaneous use, hot swappable)
Duration	Internal > 7 h (2 batteries), External > 8.5 h (room temp.)

Environmental

Operating temperature	–20° C to +50° C / –4° F to 122° F
Storage temperature	–40° C to +70° C / –40° F to 158° F
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing
Dust/Humidity	IP54 (IEC 60529)

Physical

Scanner	
Dimensions (D x W x H)	238 mm x 358 mm x 395 mm / 9.4" x 14.1" x 15.6"
Weight	11.9 kg / 26.2 lbs, nominal (w/o batteries)
Battery (internal)	
Dimensions (D x W x H)	40 mm x 72 mm x 77 mm / 1.6" x 2.8" x 3.0"
Weight	0.4 kg / 0.9 lbs
Battery (external)	
Dimensions (D x W x H)	95 mm x 248 mm x 60 mm / 3.7" x 9.8" x 2.4"
Weight	1.9 kg / 4.2 lbs
AC Power Supply	
Dimensions (D x W x H)	170 mm x 85 mm x 42.5 mm / 6.6" x 3.3" x 1.6"
Weight	0.86 kg / 1.9 lbs
Mounting	Upright or upside down

Standard Accessories Included

Scanner transport case
Tribrach (Leica Geosystems Professional Series)
4 x Internal batteries
Battery charger / AC power cable, car adapter, daisy chain cable
Data cable
Height metre and distance holder for height metre
1 year CCP Basic support contract

Additional Accessories & Services

B&W scan targets and target accessories
Range of Customer Care Products (CCPs) that include Support, Hardware & Software maintenance and Extended warranty.
External battery with charging station, AC power supply and power cable
Professional charger for internal batteries
AC power supply for scanner
Tripod and tripod star
Upside down mounting adapter

Control Options

Full colour touchscreen for onboard scan control.
Remote control: Leica CS10/CS15 controller or any other remote desktop capable device, including iPad, iPhone and other SmartPhones.

Ordering Information

Contact your local Leica Geosystems representative or an authorized Leica Geosystems dealer.

All specifications are subject to change without notice.
All accuracy specifications are one sigma unless otherwise noted.
* Algorithmic fit to planar B&W targets
** Detailed explanation on request

Scanner: Laser class 1 in accordance with IEC60825:2014
Laser plummet: Laser class 1 in accordance with IEC60825:2014

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Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com/hds

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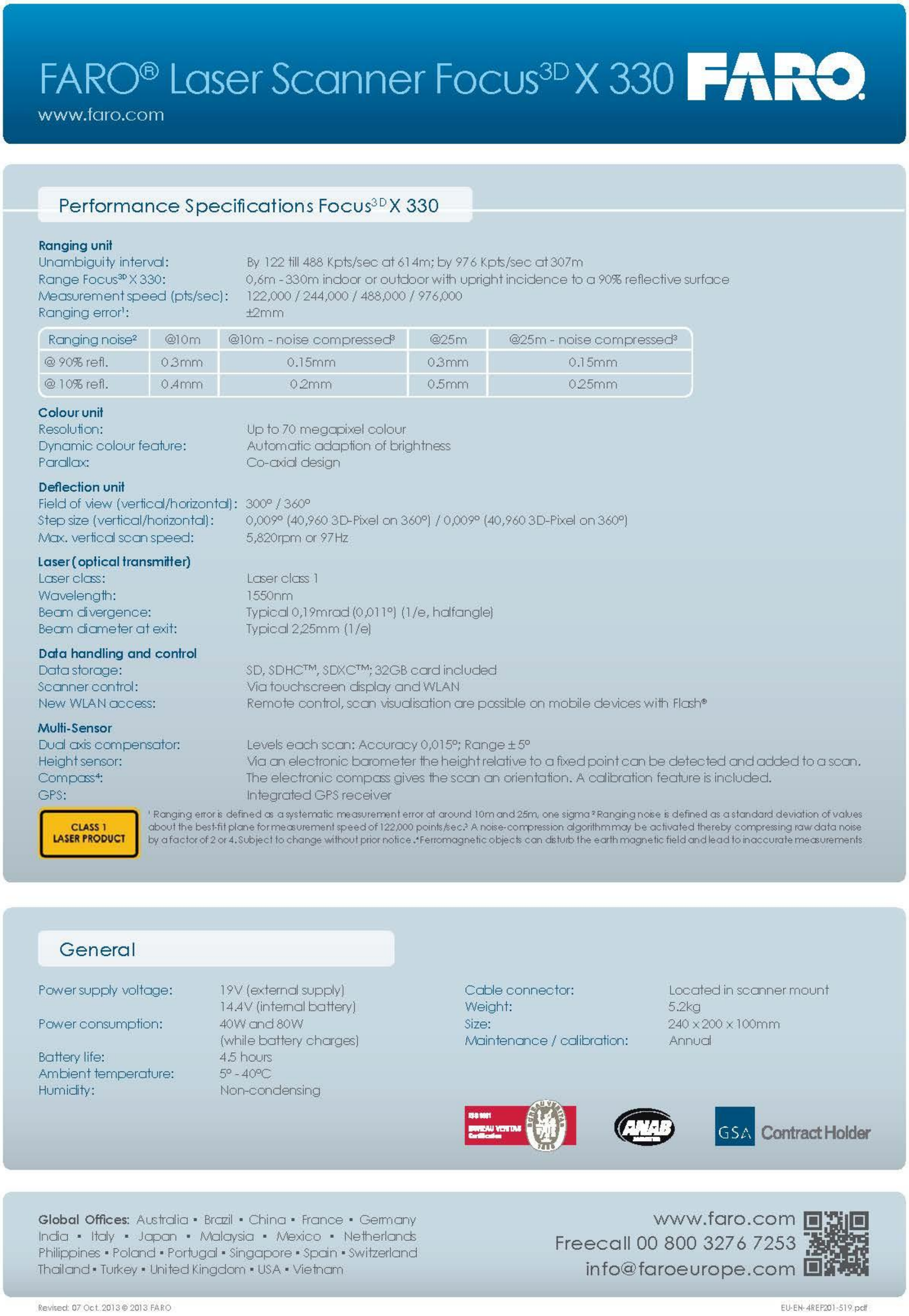
Appendix F. Faro Focus 3D X330 Specification



FARO® Laser Scanner Focus^{3D} X 330

www.faro.com

Performance Specifications Focus^{3D} X 330

Ranging unit

Unambiguity interval:	By 122 till 488 Kpts/sec at 614m; by 976 Kpts/sec at 307m
Range Focus^{3D} X 330:	0,6m - 330m indoor or outdoor with upright incidence to a 90% reflective surface
Measurement speed (pts/sec):	122,000 / 244,000 / 488,000 / 976,000
Ranging error[1]:	±2mm

Ranging noise[2]	@10m	@10m - noise compressed[3]	@25m	@25m - noise compressed[3]
@ 90% refl.	0.3mm	0.15mm	0.3mm	0.15mm
@ 10% refl.	0.4mm	0.2mm	0.5mm	0.25mm

Colour unit

Resolution:	Up to 70 megapixel colour
Dynamic colour feature:	Automatic adaption of brightness
Parallax:	Co-axial design

Deflection unit

Field of view (vertical/horizontal):	300° / 360°
Step size (vertical/horizontal):	0,009° (40,960 3D-Pixel on 360°) / 0,009° (40,960 3D-Pixel on 360°)
Max. vertical scan speed:	5,820rpm or 97Hz

Laser (optical transmitter)

Laser class:	Laser class 1
Wavelength:	1550nm
Beam divergence:	Typical 0,19mrad (0,011°) (1/e, halfangle)
Beam diameter at exit:	Typical 2,25mm (1/e)

Data handling and control

Data storage:	SD, SDHC™, SDXC™; 32GB card included
Scanner control:	Via touchscreen display and WLAN
New WLAN access:	Remote control, scan visualisation are possible on mobile devices with Flash®

Multi-Sensor

Dual axis compensator:	Levels each scan: Accuracy 0,015°; Range ± 5°
Height sensor:	Via an electronic barometer the height relative to a fixed point can be detected and added to a scan.
Compass[4]:	The electronic compass gives the scan an orientation. A calibration feature is included.
GPS:	Integrated GPS receiver

CLASS 1
LASER PRODUCT

[1] Ranging error is defined as a systematic measurement error at around 10m and 25m, one sigma [2] Ranging noise is defined as a standard deviation of values about the best-fit plane for measurement speed of 122,000 points/sec.[3] A noise-compression algorithm may be activated thereby compressing raw data noise by a factor of 2 or 4. Subject to change without prior notice. [4] Ferromagnetic objects can disturb the earth magnetic field and lead to inaccurate measurements

General

Power supply voltage:	19V (external supply) 14.4V (internal battery)
Power consumption:	40W and 80W (while battery charges)
Battery life:	4.5 hours
Ambient temperature:	5° - 40°C
Humidity:	Non-condensing
Cable connector:	Located in scanner mount
Weight:	5.2kg
Size:	240 x 200 x 100mm
Maintenance / calibration:	Annual

GSA Contract Holder

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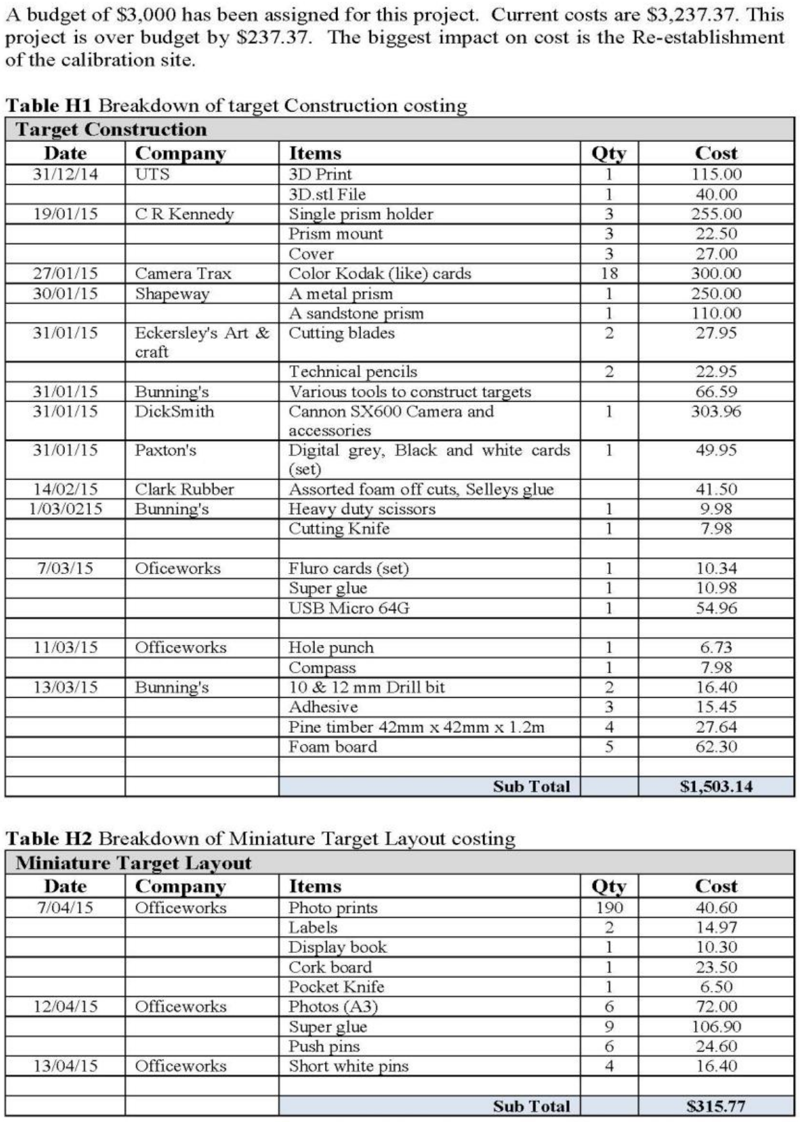
Appendix G. Project Costings



A budget of $3,000 has been assigned for this project. Current costs are $3,237.37. This project is over budget by $237.37. The biggest impact on cost is the Re-establishment of the calibration site.

Table H1 Breakdown of target Construction costing

Target Construction				
Date	**Company**	**Items**	**Qty**	**Cost**
31/12/14	UTS	3D Print	1	115.00
		3D.stl File	1	40.00
19/01/15	C R Kennedy	Single prism holder	3	255.00
		Prism mount	3	22.50
		Cover	3	27.00
27/01/15	Camera Trax	Color Kodak (like) cards	18	300.00
30/01/15	Shapeway	A metal prism	1	250.00
		A sandstone prism	1	110.00
31/01/15	Eckersley's Art & craft	Cutting blades	2	27.95
		Technical pencils	2	22.95
31/01/15	Bunning's	Various tools to construct targets		66.59
31/01/15	DickSmith	Cannon SX600 Camera and accessories	1	303.96
31/01/15	Paxton's	Digital grey, Black and white cards (set)	1	49.95
14/02/15	Clark Rubber	Assorted foam off cuts, Selleys glue		41.50
1/03/0215	Bunning's	Heavy duty scissors	1	9.98
		Cutting Knife	1	7.98
7/03/15	Oficeworks	Fluro cards (set)	1	10.34
		Super glue	1	10.98
		USB Micro 64G	1	54.96
11/03/15	Officeworks	Hole punch	1	6.73
		Compass	1	7.98
13/03/15	Bunning's	10 & 12 mm Drill bit	2	16.40
		Adhesive	3	15.45
		Pine timber 42mm x 42mm x 1.2m	4	27.64
		Foam board	5	62.30
		Sub Total		**$1,503.14**

Table H2 Breakdown of Miniature Target Layout costing

Miniature Target Layout				
Date	**Company**	**Items**	**Qty**	**Cost**
7/04/15	Officeworks	Photo prints	190	40.60
		Labels	2	14.97
		Display book	1	10.30
		Cork board	1	23.50
		Pocket Knife	1	6.50
12/04/15	Officeworks	Photos (A3)	6	72.00
		Super glue	9	106.90
		Push pins	6	24.60
13/04/15	Officeworks	Short white pins	4	16.40
		Sub Total		**$315.77**

Table H3 Breakdown of Target Installation costing

Target Installation				
Date	**Company**	**Items**	**Qty**	**Cost**
7/04/15	Officeworks	Adhesive, gaffer tape, aluminum frame		29.47
14/04/15	Bunning's	Velkro sets	30	168.59
		Gaffe Tape	2	20.40
12/05/15	Storage King	Calibration site re-establishment		1200.00
		9m x 4m x 3m		
		A one month rental 18 June to 18 July		
		Sub Total		**$1,418.46**

Table H4 Total Costing of the Project work

				Total Costing
		Target Construction		1503.14
		Miniature Target Layout		315.77
		Target Installation		1418.46
		Total		**$3,237.37**

Appendix H. Calibration Reports Leica TS15 & TS30

Report No. Bankst13

MEASUREMENT REPORT

BANKSTOWN EDM TESTLINE

ACCESS : Unrestricted (10mm Allen key required to remove pillar caps)

HORIZONTAL DISTANCES (metres) AT DATUM 47.484 m AHD

From	To	Distance	Mark	RL (AHD) *
PM 58055	PM 58056	202.078	PM 58055	47.484
PM 58055	PM 58057	458.736	PM 58056	48.445
PM 58055	PM 58058	605.010	PM 58057	50.739
			PM 58058	57.634

* The Reduced Levels (in metres AHD) were not re-verified at this date.

Method of verification: VA-QM-01 and NMI's Verifying Authorities Handbook, 2nd Ed. November 1988

Distances by the Surveyor-General of NSW, in accordance with the verification of a Reference standard of length as prescribed by the National Measurement Act 1960.

Instrument used : Leica TS 30, Serial No. 360783
Verified in accordance with Regulation 13 of the National Measurement Regulations 1999

Uncertainty of distances: +/- (0.5mm + 1.3ppm)

This uncertainty is calculated in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement, with an interval estimated to have a confidence level of 95% and a coverage factor of 2. The uncertainty applies at the time of measurement only and takes no account of pillar movement that may occur after the date of verification.

Accredited for compliance with ISO/IEC 17025.
The results of the tests, calibrations and/or measurements included in this document are traceable to Australian national standards.
This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14965

R. K. Lock date 9/4/13
Surveyor
Legal Metrology Officer
for the Surveyor-General of NSW

Date of Verification: 26 March 2013

Land and Property Information
1 Prince Albert Road, Queens Square, GPO Box 15, Sydney NSW 2001
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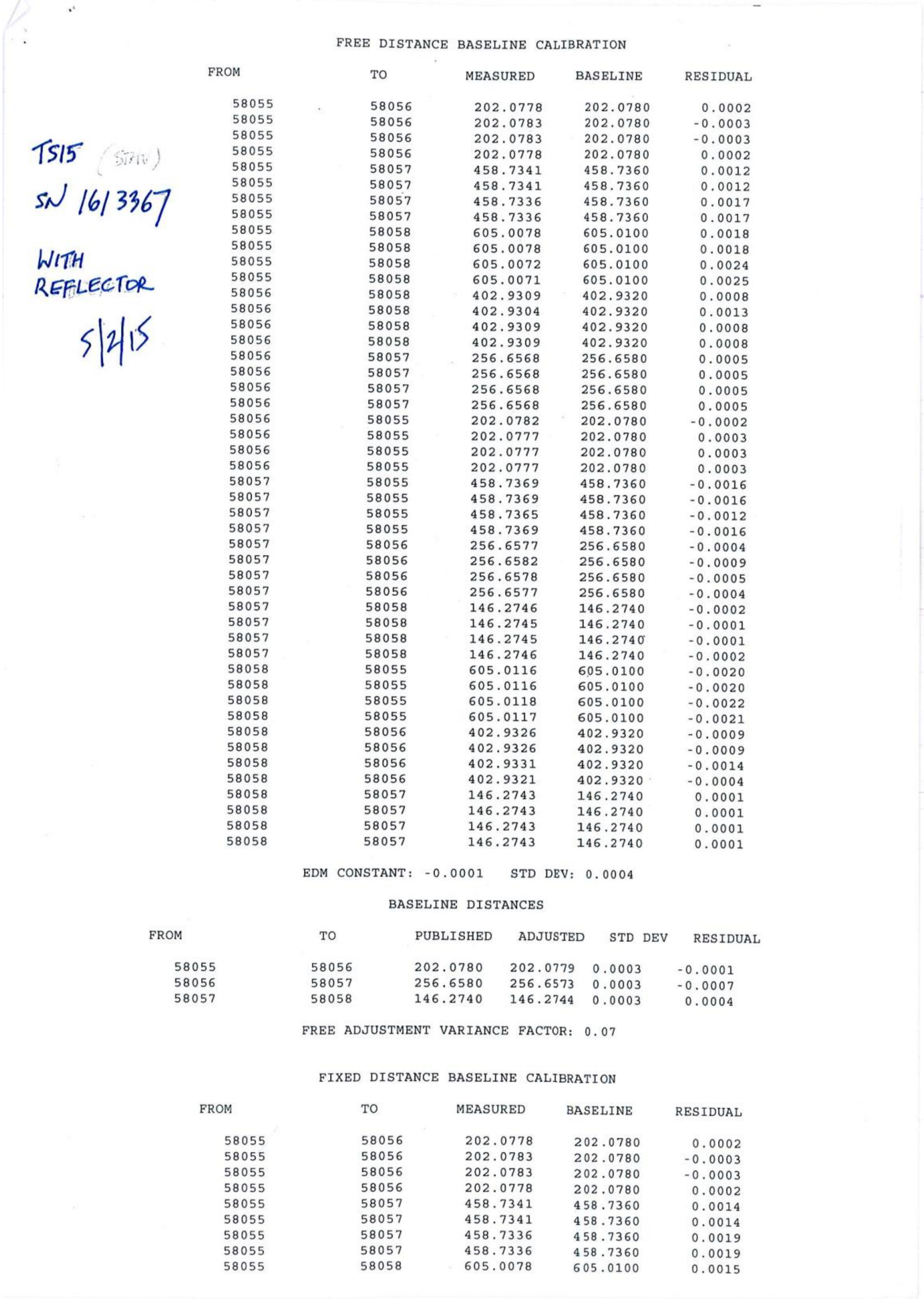
Page 1 of 1



TS15 (STATN)

SN 1613367

WITH REFLECTOR

5/2/15

```
                   FREE DISTANCE BASELINE CALIBRATION
     FROM              TO      MEASURED     BASELINE     RESIDUAL

       58055          58056    202.0778     202.0780       0.0002
       58055          58056    202.0783     202.0780      -0.0003
       58055          58056    202.0783     202.0780      -0.0003
       58055          58056    202.0778     202.0780       0.0002
       58055          58057    458.7341     458.7360       0.0012
       58055          58057    458.7341     458.7360       0.0012
       58055          58057    458.7336     458.7360       0.0017
       58055          58057    458.7336     458.7360       0.0017
       58055          58058    605.0078     605.0100       0.0018
       58055          58058    605.0078     605.0100       0.0018
       58055          58058    605.0072     605.0100       0.0024
       58055          58058    605.0071     605.0100       0.0025
       58056          58058    402.9309     402.9320       0.0008
       58056          58058    402.9304     402.9320       0.0013
       58056          58058    402.9309     402.9320       0.0008
       58056          58058    402.9309     402.9320       0.0008
       58056          58057    256.6568     256.6580       0.0005
       58056          58057    256.6568     256.6580       0.0005
       58056          58057    256.6568     256.6580       0.0005
       58056          58057    256.6568     256.6580       0.0005
       58056          58055    202.0782     202.0780      -0.0002
       58056          58055    202.0777     202.0780       0.0003
       58056          58055    202.0777     202.0780       0.0003
       58056          58055    202.0777     202.0780       0.0003
       58057          58055    458.7369     458.7360      -0.0016
       58057          58055    458.7369     458.7360      -0.0016
       58057          58055    458.7365     458.7360      -0.0012
       58057          58055    458.7369     458.7360      -0.0016
       58057          58056    256.6577     256.6580      -0.0004
       58057          58056    256.6582     256.6580      -0.0009
       58057          58056    256.6578     256.6580      -0.0005
       58057          58056    256.6577     256.6580      -0.0004
       58057          58058    146.2746     146.2740      -0.0002
       58057          58058    146.2745     146.2740      -0.0001
       58057          58058    146.2745     146.2740      -0.0001
       58057          58058    146.2746     146.2740      -0.0002
       58058          58055    605.0116     605.0100      -0.0020
       58058          58055    605.0116     605.0100      -0.0020
       58058          58055    605.0118     605.0100      -0.0022
       58058          58055    605.0117     605.0100      -0.0021
       58058          58056    402.9326     402.9320      -0.0009
       58058          58056    402.9326     402.9320      -0.0009
       58058          58056    402.9331     402.9320      -0.0014
       58058          58056    402.9321     402.9320      -0.0004
       58058          58057    146.2743     146.2740       0.0001
       58058          58057    146.2743     146.2740       0.0001
       58058          58057    146.2743     146.2740       0.0001
       58058          58057    146.2743     146.2740       0.0001

              EDM CONSTANT: -0.0001    STD DEV: 0.0004

                         BASELINE DISTANCES
FROM               TO        PUBLISHED   ADJUSTED   STD DEV   RESIDUAL

  58055           58056      202.0780    202.0779   0.0003    -0.0001
  58056           58057      256.6580    256.6573   0.0003    -0.0007
  58057           58058      146.2740    146.2744   0.0003     0.0004

              FREE ADJUSTMENT VARIANCE FACTOR: 0.07

                  FIXED DISTANCE BASELINE CALIBRATION
     FROM              TO      MEASURED     BASELINE     RESIDUAL

       58055          58056    202.0778     202.0780       0.0002
       58055          58056    202.0783     202.0780      -0.0003
       58055          58056    202.0783     202.0780      -0.0003
       58055          58056    202.0778     202.0780       0.0002
       58055          58057    458.7341     458.7360       0.0014
       58055          58057    458.7341     458.7360       0.0014
       58055          58057    458.7336     458.7360       0.0019
       58055          58057    458.7336     458.7360       0.0019
       58055          58058    605.0078     605.0100       0.0015
```

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58055          58058       605.0078      605.0100        0.0015
58055          58058       605.0072      605.0100        0.0021
58055          58058       605.0071      605.0100        0.0022
58056          58058       402.9309      402.9320        0.0007
58056          58058       402.9304      402.9320        0.0012
58056          58058       402.9309      402.9320        0.0007
58056          58058       402.9309      402.9320        0.0007
58056          58057       256.6568      256.6580        0.0011
58056          58057       256.6568      256.6580        0.0011
58056          58057       256.6568      256.6580        0.0011
58056          58057       256.6568      256.6580        0.0011
58056          58055       202.0782      202.0780       -0.0002
58056          58055       202.0777      202.0780        0.0003
58056          58055       202.0777      202.0780        0.0003
58056          58055       202.0777      202.0780        0.0003
58057          58055       458.7369      458.7360       -0.0014
58057          58055       458.7369      458.7360       -0.0014
58057          58055       458.7365      458.7360       -0.0010
58057          58055       458.7369      458.7360       -0.0014
58057          58056       256.6577      256.6580        0.0002
58057          58056       256.6582      256.6580       -0.0003
58057          58056       256.6578      256.6580        0.0001
58057          58056       256.6577      256.6580        0.0002
58057          58058       146.2746      146.2740       -0.0005
58057          58058       146.2745      146.2740       -0.0004
58057          58058       146.2745      146.2740       -0.0004
58057          58058       146.2746      146.2740       -0.0005
58058          58055       605.0116      605.0100       -0.0023
58058          58055       605.0116      605.0100       -0.0023
58058          58055       605.0118      605.0100       -0.0025
58058          58055       605.0117      605.0100       -0.0024
58058          58056       402.9326      402.9320       -0.0010
58058          58056       402.9326      402.9320       -0.0010
58058          58056       402.9331      402.9320       -0.0015
58058          58056       402.9321      402.9320       -0.0005
58058          58057       146.2743      146.2740       -0.0002
58058          58057       146.2743      146.2740       -0.0002
58058          58057       146.2743      146.2740       -0.0002
58058          58057       146.2743      146.2740       -0.0002

         EDM CONSTANT: -0.0003   Std Dev: 0.0003
        PPM CORRECTION: 1.7   Std Dev: 1.0

        FIXED ADJUSTMENT VARIANCE FACTOR: 0.07
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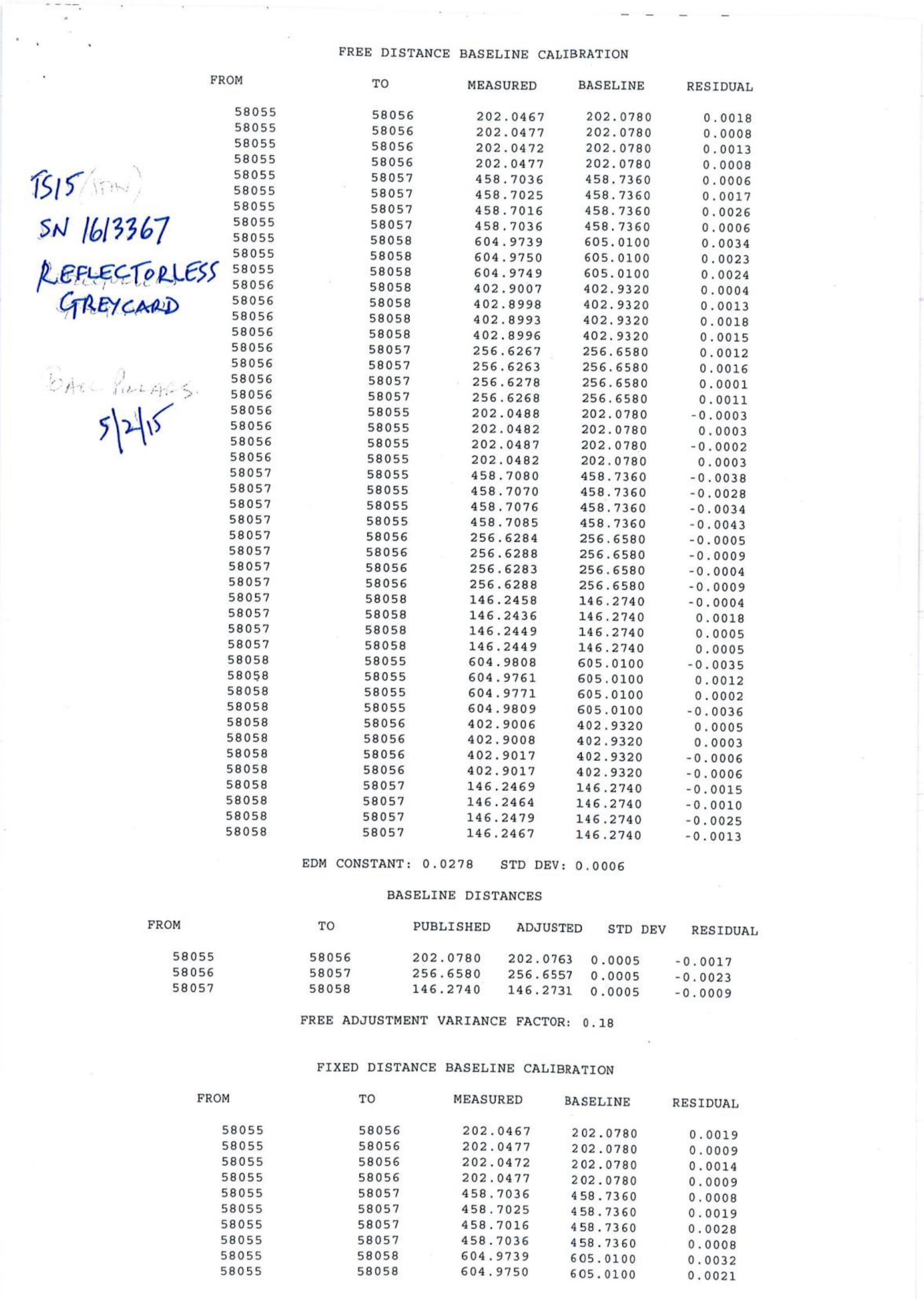

TS15 (STN)

SN 1613367

REFLECTORLESS

GREYCARD

BACK PILLARS.

5/2/15

```
                         FREE DISTANCE BASELINE CALIBRATION
           FROM               TO          MEASURED       BASELINE        RESIDUAL

              58055          58056        202.0467       202.0780        0.0018
              58055          58056        202.0477       202.0780        0.0008
              58055          58056        202.0472       202.0780        0.0013
              58055          58056        202.0477       202.0780        0.0008
              58055          58057        458.7036       458.7360        0.0006
              58055          58057        458.7025       458.7360        0.0017
              58055          58057        458.7016       458.7360        0.0026
              58055          58057        458.7036       458.7360        0.0006
              58055          58058        604.9739       605.0100        0.0034
              58055          58058        604.9750       605.0100        0.0023
              58055          58058        604.9749       605.0100        0.0024
              58056          58058        402.9007       402.9320        0.0004
              58056          58058        402.8998       402.9320        0.0013
              58056          58058        402.8993       402.9320        0.0018
              58056          58058        402.8996       402.9320        0.0015
              58056          58057        256.6267       256.6580        0.0012
              58056          58057        256.6263       256.6580        0.0016
              58056          58057        256.6278       256.6580        0.0001
              58056          58057        256.6268       256.6580        0.0011
              58056          58055        202.0488       202.0780       -0.0003
              58056          58055        202.0482       202.0780        0.0003
              58056          58055        202.0487       202.0780       -0.0002
              58056          58055        202.0482       202.0780        0.0003
              58057          58055        458.7080       458.7360       -0.0038
              58057          58055        458.7070       458.7360       -0.0028
              58057          58055        458.7076       458.7360       -0.0034
              58057          58055        458.7085       458.7360       -0.0043
              58057          58056        256.6284       256.6580       -0.0005
              58057          58056        256.6288       256.6580       -0.0009
              58057          58056        256.6283       256.6580       -0.0004
              58057          58056        256.6288       256.6580       -0.0009
              58057          58058        146.2458       146.2740       -0.0004
              58057          58058        146.2436       146.2740        0.0018
              58057          58058        146.2449       146.2740        0.0005
              58057          58058        146.2449       146.2740        0.0005
              58058          58055        604.9808       605.0100       -0.0035
              58058          58055        604.9761       605.0100        0.0012
              58058          58055        604.9771       605.0100        0.0002
              58058          58055        604.9809       605.0100       -0.0036
              58058          58056        402.9006       402.9320        0.0005
              58058          58056        402.9008       402.9320        0.0003
              58058          58056        402.9017       402.9320       -0.0006
              58058          58056        402.9017       402.9320       -0.0006
              58058          58057        146.2469       146.2740       -0.0015
              58058          58057        146.2464       146.2740       -0.0010
              58058          58057        146.2479       146.2740       -0.0025
              58058          58057        146.2467       146.2740       -0.0013

                     EDM CONSTANT: 0.0278    STD DEV: 0.0006

                              BASELINE DISTANCES

   FROM                 TO          PUBLISHED    ADJUSTED    STD DEV    RESIDUAL

     58055             58056        202.0780     202.0763    0.0005     -0.0017
     58056             58057        256.6580     256.6557    0.0005     -0.0023
     58057             58058        146.2740     146.2731    0.0005     -0.0009

                    FREE ADJUSTMENT VARIANCE FACTOR: 0.18

                        FIXED DISTANCE BASELINE CALIBRATION

          FROM               TO          MEASURED       BASELINE        RESIDUAL

             58055          58056        202.0467       202.0780        0.0019
             58055          58056        202.0477       202.0780        0.0009
             58055          58056        202.0472       202.0780        0.0014
             58055          58056        202.0477       202.0780        0.0009
             58055          58057        458.7036       458.7360        0.0008
             58055          58057        458.7025       458.7360        0.0019
             58055          58057        458.7016       458.7360        0.0028
             58055          58057        458.7036       458.7360        0.0008
             58055          58058        604.9739       605.0100        0.0032
             58055          58058        604.9750       605.0100        0.0021
```

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58055        58058     604.9749    605.0100     0.0022
58056        58058     402.9007    402.9320     0.0002
58056        58058     402.8998    402.9320     0.0011
58056        58058     402.8993    402.9320     0.0016
58056        58058     402.8996    402.9320     0.0013
58056        58057     256.6267    256.6580     0.0015
58056        58057     256.6263    256.6580     0.0019
58056        58057     256.6278    256.6580     0.0004
58056        58057     256.6268    256.6580     0.0014
58056        58055     202.0488    202.0780    -0.0002
58056        58055     202.0482    202.0780     0.0004
58056        58055     202.0487    202.0780    -0.0001
58056        58055     202.0482    202.0780     0.0004
58057        58055     458.7080    458.7360    -0.0036
58057        58055     458.7070    458.7360    -0.0026
58057        58055     458.7076    458.7360    -0.0032
58057        58055     458.7085    458.7360    -0.0041
58057        58056     256.6284    256.6580    -0.0002
58057        58056     256.6288    256.6580    -0.0006
58057        58056     256.6283    256.6580    -0.0001
58057        58056     256.6288    256.6580    -0.0006
58057        58058     146.2458    146.2740    -0.0007
58057        58058     146.2436    146.2740     0.0015
58057        58058     146.2449    146.2740     0.0002
58057        58058     146.2449    146.2740     0.0002
58058        58055     604.9808    605.0100    -0.0037
58058        58055     604.9761    605.0100     0.0010
58058        58055     604.9771    605.0100     0.0000
58058        58055     604.9809    605.0100    -0.0038
58058        58056     402.9006    402.9320     0.0003
58058        58056     402.9008    402.9320     0.0001
58058        58056     402.9017    402.9320    -0.0008
58058        58056     402.9017    402.9320    -0.0008
58058        58057     146.2469    146.2740    -0.0018
58058        58057     146.2464    146.2740    -0.0013
58058        58057     146.2479    146.2740    -0.0028
58058        58057     146.2467    146.2740    -0.0016

      EDM CONSTANT: 0.0276   Std Dev: 0.0005
     PPM CORRECTION: 8.7   Std Dev: 1.6

     FIXED ADJUSTMENT VARIANCE FACTOR: 0.17
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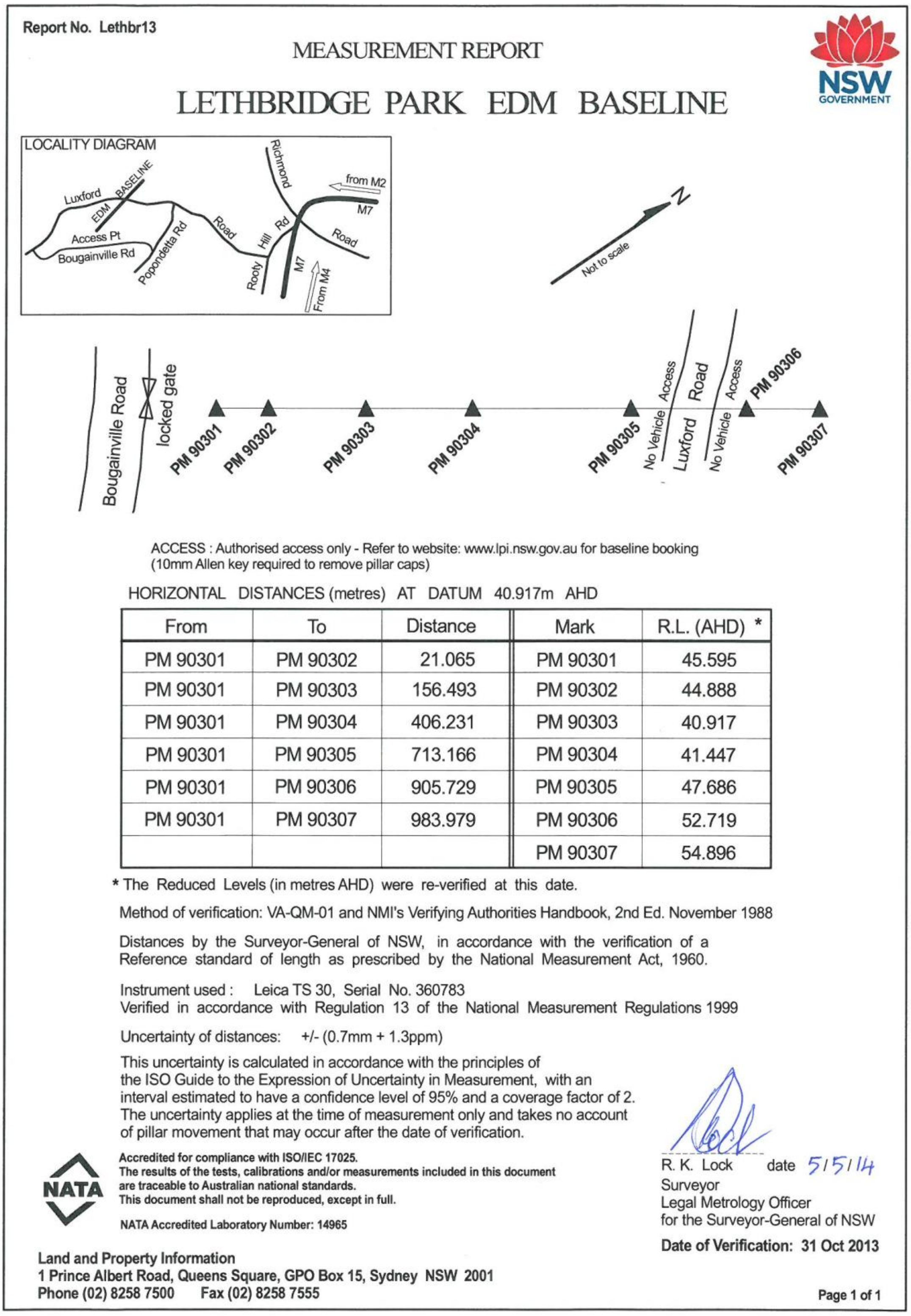


Report No. Lethbr13

MEASUREMENT REPORT

LETHBRIDGE PARK EDM BASELINE

ACCESS : Authorised access only - Refer to website: www.lpi.nsw.gov.au for baseline booking
(10mm Allen key required to remove pillar caps)

HORIZONTAL DISTANCES (metres) AT DATUM 40.917m AHD

From	To	Distance	Mark	R.L. (AHD) *
PM 90301	PM 90302	21.065	PM 90301	45.595
PM 90301	PM 90303	156.493	PM 90302	44.888
PM 90301	PM 90304	406.231	PM 90303	40.917
PM 90301	PM 90305	713.166	PM 90304	41.447
PM 90301	PM 90306	905.729	PM 90305	47.686
PM 90301	PM 90307	983.979	PM 90306	52.719
			PM 90307	54.896

* The Reduced Levels (in metres AHD) were re-verified at this date.

Method of verification: VA-QM-01 and NMI's Verifying Authorities Handbook, 2nd Ed. November 1988

Distances by the Surveyor-General of NSW, in accordance with the verification of a Reference standard of length as prescribed by the National Measurement Act, 1960.

Instrument used : Leica TS 30, Serial No. 360783
Verified in accordance with Regulation 13 of the National Measurement Regulations 1999

Uncertainty of distances: +/- (0.7mm + 1.3ppm)

This uncertainty is calculated in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement, with an interval estimated to have a confidence level of 95% and a coverage factor of 2. The uncertainty applies at the time of measurement only and takes no account of pillar movement that may occur after the date of verification.

Accredited for compliance with ISO/IEC 17025.
The results of the tests, calibrations and/or measurements included in this document are traceable to Australian national standards.
This document shall not be reproduced, except in full.

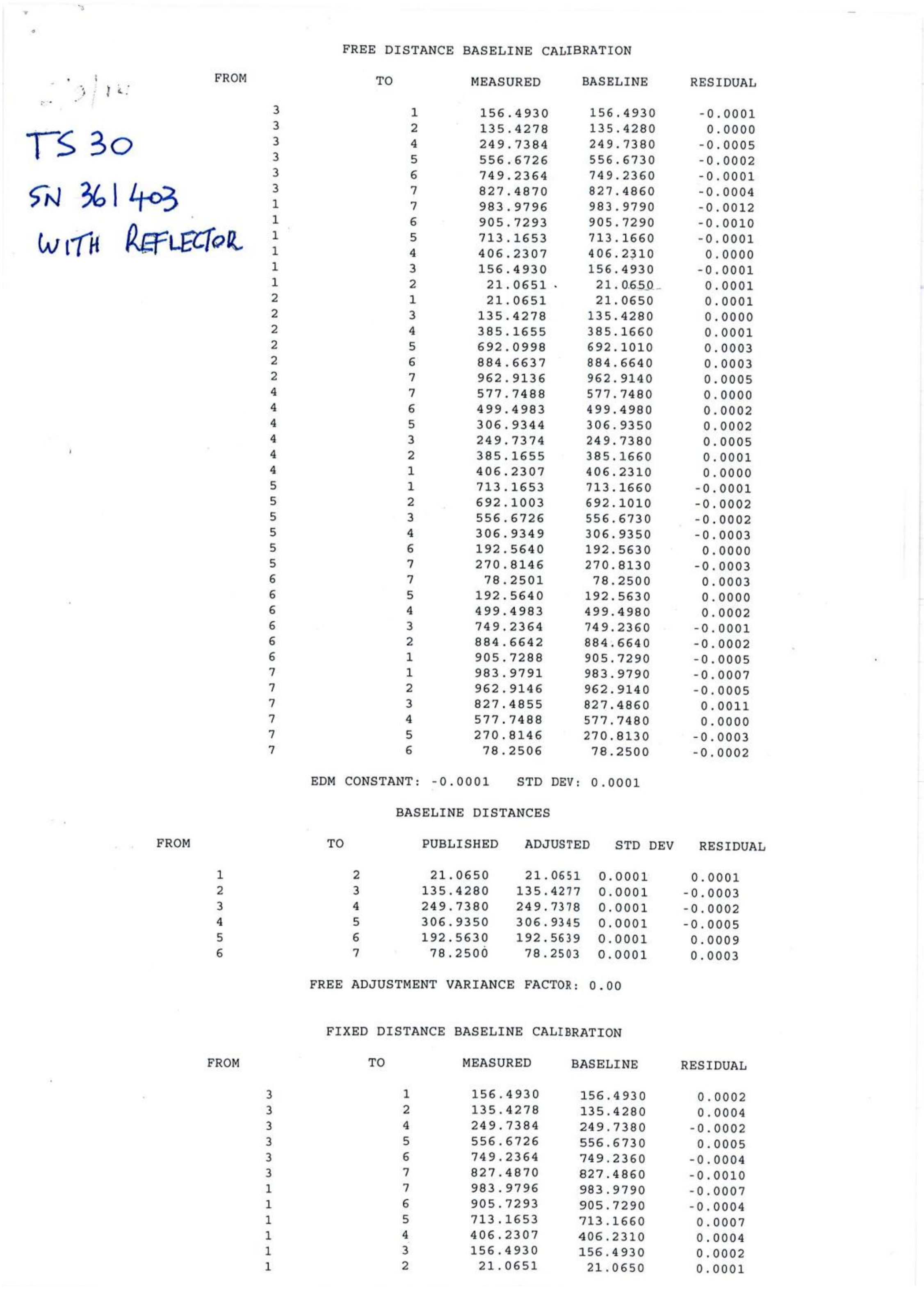
NATA Accredited Laboratory Number: 14965

R. K. Lock date 5/5/14
Surveyor
Legal Metrology Officer
for the Surveyor-General of NSW

Date of Verification: 31 Oct 2013

Land and Property Information
1 Prince Albert Road, Queens Square, GPO Box 15, Sydney NSW 2001
Phone (02) 8258 7500 Fax (02) 8258 7555

Page 1 of 1



3/14

TS 30

SN 361403

WITH REFLECTOR

```
                         FREE DISTANCE BASELINE CALIBRATION

             FROM            TO        MEASURED     BASELINE     RESIDUAL

                     3        1        156.4930     156.4930     -0.0001
                     3        2        135.4278     135.4280      0.0000
                     3        4        249.7384     249.7380     -0.0005
                     3        5        556.6726     556.6730     -0.0002
                     3        6        749.2364     749.2360     -0.0001
                     3        7        827.4870     827.4860     -0.0004
                     1        7        983.9796     983.9790     -0.0012
                     1        6        905.7293     905.7290     -0.0010
                     1        5        713.1653     713.1660     -0.0001
                     1        4        406.2307     406.2310      0.0000
                     1        3        156.4930     156.4930     -0.0001
                     1        2         21.0651      21.0650      0.0001
                     2        1         21.0651      21.0650      0.0001
                     2        3        135.4278     135.4280      0.0000
                     2        4        385.1655     385.1660      0.0001
                     2        5        692.0998     692.1010      0.0003
                     2        6        884.6637     884.6640      0.0003
                     2        7        962.9136     962.9140      0.0005
                     4        7        577.7488     577.7480      0.0000
                     4        6        499.4983     499.4980      0.0002
                     4        5        306.9344     306.9350      0.0002
                     4        3        249.7374     249.7380      0.0005
                     4        2        385.1655     385.1660      0.0001
                     4        1        406.2307     406.2310      0.0000
                     5        1        713.1653     713.1660     -0.0001
                     5        2        692.1003     692.1010     -0.0002
                     5        3        556.6726     556.6730     -0.0002
                     5        4        306.9349     306.9350     -0.0003
                     5        6        192.5640     192.5630      0.0000
                     5        7        270.8146     270.8130     -0.0003
                     6        7         78.2501      78.2500      0.0003
                     6        5        192.5640     192.5630      0.0000
                     6        4        499.4983     499.4980      0.0002
                     6        3        749.2364     749.2360     -0.0001
                     6        2        884.6642     884.6640     -0.0002
                     6        1        905.7288     905.7290     -0.0005
                     7        1        983.9791     983.9790     -0.0007
                     7        2        962.9146     962.9140     -0.0005
                     7        3        827.4855     827.4860      0.0011
                     7        4        577.7488     577.7480      0.0000
                     7        5        270.8146     270.8130     -0.0003
                     7        6         78.2506      78.2500     -0.0002

                      EDM CONSTANT: -0.0001    STD DEV: 0.0001

                              BASELINE DISTANCES

        FROM            TO        PUBLISHED   ADJUSTED   STD DEV   RESIDUAL

              1          2         21.0650    21.0651    0.0001     0.0001
              2          3        135.4280   135.4277    0.0001    -0.0003
              3          4        249.7380   249.7378    0.0001    -0.0002
              4          5        306.9350   306.9345    0.0001    -0.0005
              5          6        192.5630   192.5639    0.0001     0.0009
              6          7         78.2500    78.2503    0.0001     0.0003

                      FREE ADJUSTMENT VARIANCE FACTOR: 0.00


                        FIXED DISTANCE BASELINE CALIBRATION

             FROM            TO        MEASURED     BASELINE     RESIDUAL

                     3        1        156.4930     156.4930      0.0002
                     3        2        135.4278     135.4280      0.0004
                     3        4        249.7384     249.7380     -0.0002
                     3        5        556.6726     556.6730      0.0005
                     3        6        749.2364     749.2360     -0.0004
                     3        7        827.4870     827.4860     -0.0010
                     1        7        983.9796     983.9790     -0.0007
                     1        6        905.7293     905.7290     -0.0004
                     1        5        713.1653     713.1660      0.0007
                     1        4        406.2307     406.2310      0.0004
                     1        3        156.4930     156.4930      0.0002
                     1        2         21.0651      21.0650      0.0001
```

```
2          1      21.0651     21.0650     0.0001
2          3     135.4278    135.4280     0.0004
2          4     385.1655    385.1660     0.0006
2          5     692.0998    692.1010     0.0012
2          6     884.6637    884.6640     0.0003
2          7     962.9136    962.9140     0.0003
4          7     577.7488    577.7480    -0.0007
4          6     499.4983    499.4980    -0.0002
4          5     306.9344    306.9350     0.0007
4          3     249.7374    249.7380     0.0008
4          2     385.1655    385.1660     0.0006
4          1     406.2307    406.2310     0.0004
5          1     713.1653    713.1660     0.0007
5          2     692.1003    692.1010     0.0007
5          3     556.6726    556.6730     0.0005
5          4     306.9349    306.9350     0.0002
5          6     192.5640    192.5630    -0.0008
5          7     270.8146    270.8130    -0.0014
6          7      78.2501     78.2500     0.0001
6          5     192.5640    192.5630    -0.0008
6          4     499.4983    499.4980    -0.0002
6          3     749.2364    749.2360    -0.0004
6          2     884.6642    884.6640    -0.0002
6          1     905.7288    905.7290     0.0001
7          1     983.9791    983.9790    -0.0002
7          2     962.9146    962.9140    -0.0007
7          3     827.4855    827.4860     0.0005
7          4     577.7488    577.7480    -0.0007
7          5     270.8146    270.8130    -0.0014
7          6      78.2506     78.2500    -0.0004

     EDM CONSTANT: -0.0002   Std Dev: 0.0001
    PPM CORRECTION: 0.3   Std Dev: 0.3

    FIXED ADJUSTMENT VARIANCE FACTOR: 0.02
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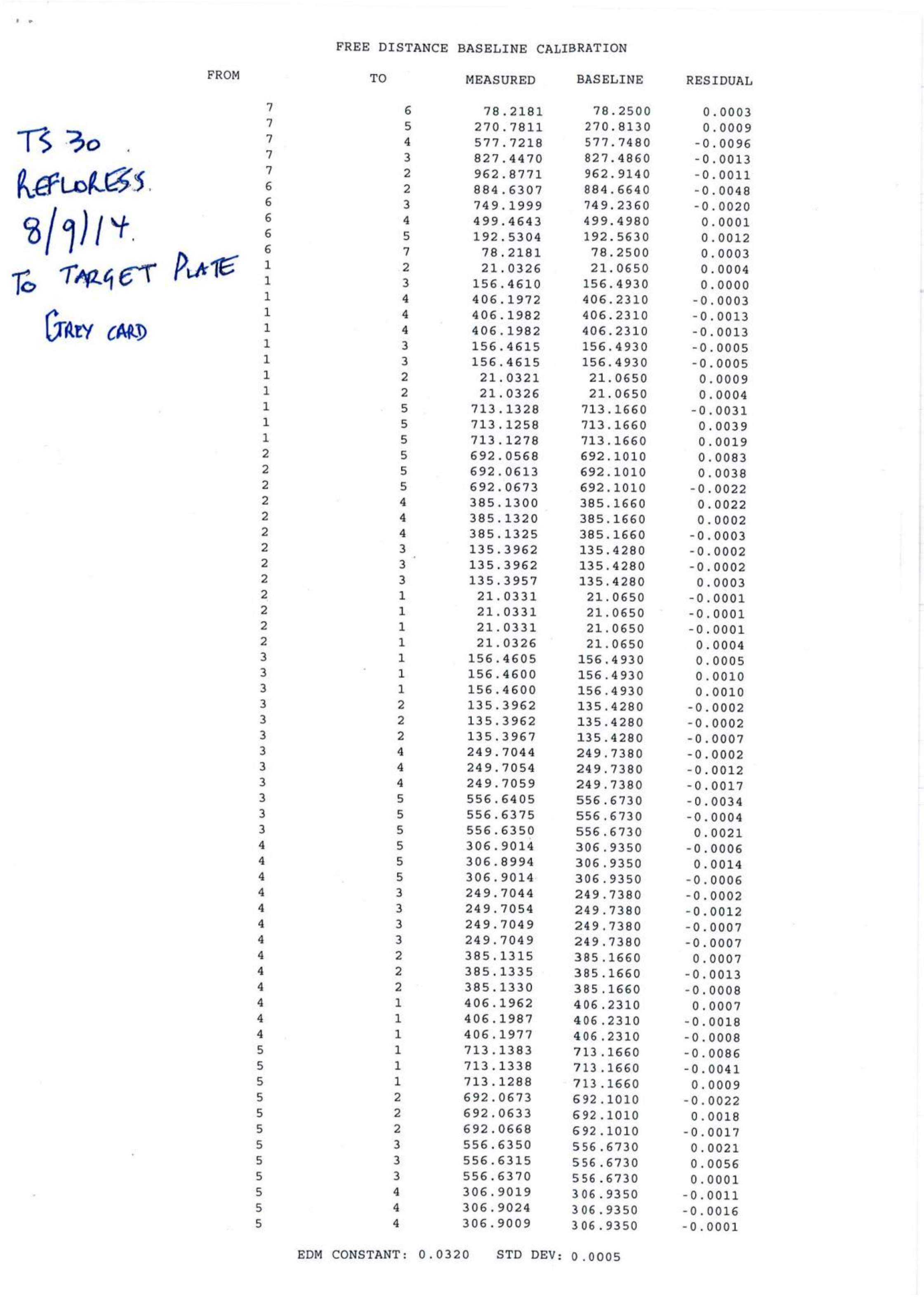
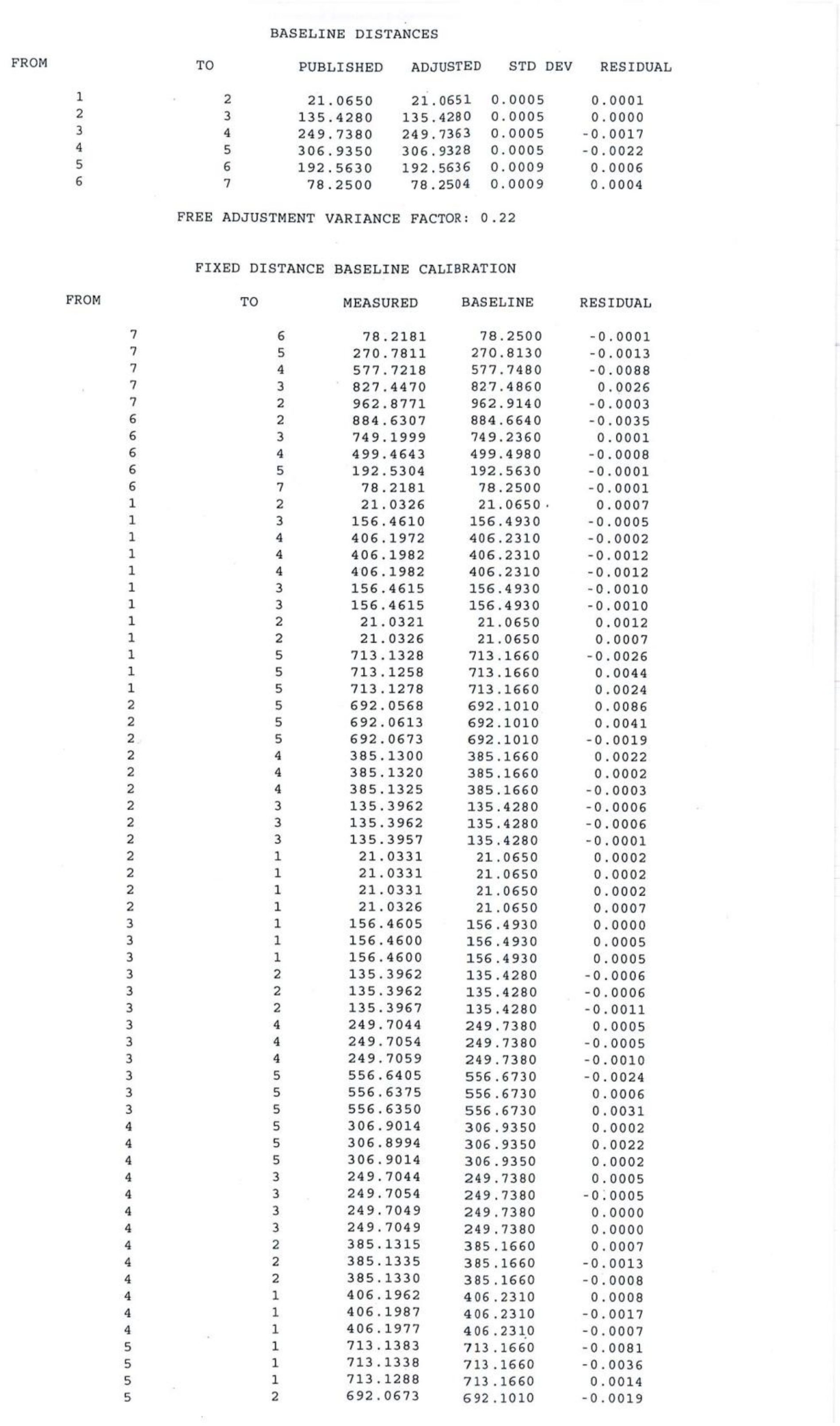


TS 30.
REFLORESS.
8/9/14.
To TARGET PLATE
GREY CARD

FREE DISTANCE BASELINE CALIBRATION

FROM	TO	MEASURED	BASELINE	RESIDUAL
7	6	78.2181	78.2500	0.0003
7	5	270.7811	270.8130	0.0009
7	4	577.7218	577.7480	-0.0096
7	3	827.4470	827.4860	-0.0013
7	2	962.8771	962.9140	-0.0011
6	2	884.6307	884.6640	-0.0048
6	3	749.1999	749.2360	-0.0020
6	4	499.4643	499.4980	0.0001
6	5	192.5304	192.5630	0.0012
6	7	78.2181	78.2500	0.0003
1	2	21.0326	21.0650	0.0004
1	3	156.4610	156.4930	0.0000
1	4	406.1972	406.2310	-0.0003
1	4	406.1982	406.2310	-0.0013
1	4	406.1982	406.2310	-0.0013
1	3	156.4615	156.4930	-0.0005
1	3	156.4615	156.4930	-0.0005
1	2	21.0321	21.0650	0.0009
1	2	21.0326	21.0650	0.0004
1	5	713.1328	713.1660	-0.0031
1	5	713.1258	713.1660	0.0039
1	5	713.1278	713.1660	0.0019
2	5	692.0568	692.1010	0.0083
2	5	692.0613	692.1010	0.0038
2	5	692.0673	692.1010	-0.0022
2	4	385.1300	385.1660	0.0022
2	4	385.1320	385.1660	0.0002
2	4	385.1325	385.1660	-0.0003
2	3	135.3962	135.4280	-0.0002
2	3	135.3962	135.4280	-0.0002
2	3	135.3957	135.4280	0.0003
2	1	21.0331	21.0650	-0.0001
2	1	21.0331	21.0650	-0.0001
2	1	21.0331	21.0650	-0.0001
2	1	21.0326	21.0650	0.0004
3	1	156.4605	156.4930	0.0005
3	1	156.4600	156.4930	0.0010
3	1	156.4600	156.4930	0.0010
3	2	135.3962	135.4280	-0.0002
3	2	135.3962	135.4280	-0.0002
3	2	135.3967	135.4280	-0.0007
3	4	249.7044	249.7380	-0.0002
3	4	249.7054	249.7380	-0.0012
3	4	249.7059	249.7380	-0.0017
3	5	556.6405	556.6730	-0.0034
3	5	556.6375	556.6730	-0.0004
3	5	556.6350	556.6730	0.0021
4	5	306.9014	306.9350	-0.0006
4	5	306.8994	306.9350	0.0014
4	5	306.9014	306.9350	-0.0006
4	3	249.7044	249.7380	-0.0002
4	3	249.7054	249.7380	-0.0012
4	3	249.7049	249.7380	-0.0007
4	3	249.7049	249.7380	-0.0007
4	2	385.1315	385.1660	0.0007
4	2	385.1335	385.1660	-0.0013
4	2	385.1330	385.1660	-0.0008
4	1	406.1962	406.2310	0.0007
4	1	406.1987	406.2310	-0.0018
4	1	406.1977	406.2310	-0.0008
5	1	713.1383	713.1660	-0.0086
5	1	713.1338	713.1660	-0.0041
5	1	713.1288	713.1660	0.0009
5	2	692.0673	692.1010	-0.0022
5	2	692.0633	692.1010	0.0018
5	2	692.0668	692.1010	-0.0017
5	3	556.6350	556.6730	0.0021
5	3	556.6315	556.6730	0.0056
5	3	556.6370	556.6730	0.0001
5	4	306.9019	306.9350	-0.0011
5	4	306.9024	306.9350	-0.0016
5	4	306.9009	306.9350	-0.0001

EDM CONSTANT: 0.0320 STD DEV: 0.0005



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                         BASELINE DISTANCES

FROM              TO          PUBLISHED    ADJUSTED    STD DEV    RESIDUAL

     1              2           21.0650     21.0651   0.0005       0.0001
     2              3          135.4280    135.4280   0.0005       0.0000
     3              4          249.7380    249.7363   0.0005      -0.0017
     4              5          306.9350    306.9328   0.0005      -0.0022
     5              6          192.5630    192.5636   0.0009       0.0006
     6              7           78.2500     78.2504   0.0009       0.0004

                FREE ADJUSTMENT VARIANCE FACTOR: 0.22


                  FIXED DISTANCE BASELINE CALIBRATION

     FROM              TO          MEASURED      BASELINE      RESIDUAL

           7              6          78.2181       78.2500       -0.0001
           7              5         270.7811      270.8130       -0.0013
           7              4         577.7218      577.7480       -0.0088
           7              3         827.4470      827.4860        0.0026
           7              2         962.8771      962.9140       -0.0003
           6              2         884.6307      884.6640       -0.0035
           6              3         749.1999      749.2360        0.0001
           6              4         499.4643      499.4980       -0.0008
           6              5         192.5304      192.5630       -0.0001
           6              7          78.2181       78.2500       -0.0001
           1              2          21.0326       21.0650        0.0007
           1              3         156.4610      156.4930       -0.0005
           1              4         406.1972      406.2310       -0.0002
           1              4         406.1982      406.2310       -0.0012
           1              4         406.1982      406.2310       -0.0012
           1              3         156.4615      156.4930       -0.0010
           1              3         156.4615      156.4930       -0.0010
           1              2          21.0321       21.0650        0.0012
           1              2          21.0326       21.0650        0.0007
           1              5         713.1328      713.1660       -0.0026
           1              5         713.1258      713.1660        0.0044
           1              5         713.1278      713.1660        0.0024
           2              5         692.0568      692.1010        0.0086
           2              5         692.0613      692.1010        0.0041
           2              5         692.0673      692.1010       -0.0019
           2              4         385.1300      385.1660        0.0022
           2              4         385.1320      385.1660        0.0002
           2              4         385.1325      385.1660       -0.0003
           2              3         135.3962      135.4280       -0.0006
           2              3         135.3962      135.4280       -0.0006
           2              3         135.3957      135.4280       -0.0001
           2              1          21.0331       21.0650        0.0002
           2              1          21.0331       21.0650        0.0002
           2              1          21.0331       21.0650        0.0002
           2              1          21.0326       21.0650        0.0007
           3              1         156.4605      156.4930        0.0000
           3              1         156.4600      156.4930        0.0005
           3              1         156.4600      156.4930        0.0005
           3              2         135.3962      135.4280       -0.0006
           3              2         135.3962      135.4280       -0.0006
           3              2         135.3967      135.4280       -0.0011
           3              4         249.7044      249.7380        0.0005
           3              4         249.7054      249.7380       -0.0005
           3              4         249.7059      249.7380       -0.0010
           3              5         556.6405      556.6730       -0.0024
           3              5         556.6375      556.6730        0.0006
           3              5         556.6350      556.6730        0.0031
           4              5         306.9014      306.9350        0.0002
           4              5         306.8994      306.9350        0.0022
           4              5         306.9014      306.9350        0.0002
           4              3         249.7044      249.7380        0.0005
           4              3         249.7054      249.7380       -0.0005
           4              3         249.7049      249.7380        0.0000
           4              3         249.7049      249.7380        0.0000
           4              2         385.1315      385.1660        0.0007
           4              2         385.1335      385.1660       -0.0013
           4              2         385.1330      385.1660       -0.0008
           4              1         406.1962      406.2310        0.0008
           4              1         406.1987      406.2310       -0.0017
           4              1         406.1977      406.2310       -0.0007
           5              1         713.1383      713.1660       -0.0081
           5              1         713.1338      713.1660       -0.0036
           5              1         713.1288      713.1660        0.0014
           5              2         692.0673      692.1010       -0.0019
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5          2     692.0633    692.1010      0.0021
5          2     692.0668    692.1010     -0.0014
5          3     556.6350    556.6730      0.0031
5          3     556.6315    556.6730      0.0066
5          3     556.6370    556.6730      0.0011
5          4     306.9019    306.9350     -0.0003
5          4     306.9024    306.9350     -0.0008
5          4     306.9009    306.9350      0.0007

     EDM CONSTANT: 0.0316   Std Dev: 0.0004
    PPM CORRECTION: 5.9   Std Dev: 1.0

    FIXED ADJUSTMENT VARIANCE FACTOR: 0.23
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