University of Southern Queensland

Faculty of Engineering and Surveying

The Use of a Terrestrial Laser Scanner in an Open Cut Mining Environment

A dissertation submitted by

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ABSTRACT

Advances in Terrestrial Laser Scanning technology in the areas of topographic data capture, represent new and exciting opportunities for the mining industry, in particular open cut coal. Terrestrial laser scanning offers an alternative to traditional survey techniques. It consists of automated high speed data capture of complex surfaces in often inaccessible environments.

The use of a TLS system has been examined in this dissertation with respect to its cost effectiveness, user friendliness and ability to comply with relevant government legislation regulating its use in the open cut coal surveys. The ability to be able to setup the TLS system in a safe location for both operator and machine and acquire all the data of a traditional survey and much more without putting the operator in the line of fire, suggests that TLS systems in dangerous working environments such as mining, will become common place in the near future.

This dissertation has been developed from the start of 2008 when the evaluation for purchase of a TLS system was undertaken, and as such prices listed for equipment are indicative for that time. Since then, the prices of TLS systems have dropped dramatically, which is a direct reflection of the markets acceptance of TLS technology and surveyor confidence in the stated accuracies of the machines.

Keywords: Terrestrial, scanning, automated, TLS, confidence.

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, 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.

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(Signature)

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(Date)

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GLOSSARY OF TERMS

The following abbreviations have been used throughout the text and bibliography:-

As Built	A model which captures the exact physical shape of an object.
CAD	Computer Aided Design.
COGO	Coordinate Geometry.
Co-ordinate System	A set of numerical values used to denote a location in 3D space.
Cartesian co-ordinate system	Three orthogonal 'world axis' (the X, Y and Z Axes) are used to define the position of a point relative to the intersection of these axes, or origin.
DXF	Drawing Exchange Format.
EDM	Electronic Distance Measurement.
Geo-referencing	The assignment of coordinates of an absolute geographic reference system to a geographic feature.
GPS	Global Positioning System.
Highwall	The unexcavated face of exposed overburden and coal in a surface mine or in a face or bank on the uphill side of a contour mine excavation.
Laser Scanning	Is the use of a laser to collect dimensional data in the form of a "point cloud".
Lowwall	An excavated face of exposed overburden and coal in a surface mine or in a face or bank on the downhill side of a contour mine excavation.
MSL	Mean Sea Level.
MTW	Mount Thorley Warkworth.
Point	A one-dimensional point in co-ordinate space.
Point cloud	A set of three-dimensional points describing the outlines or surface features of an object.
Registration	The processes of making one set of data align with another, such that both sets are in a common co-ordinate system.

RTK	Real Time Kinematic.
Surface Model	A CAD model of an object that is defined by its bounding surface.
TGO	Trimble Geomatics Office.
TOF	Time of Flight.
TLS	Terrestrial Laser Scanner.
TSCE	Trimble Survey Controller.
2D	Two Dimensional. Descriptive of a region of space that has width and height
3D	Three Dimensional. Descriptive of a region of space that has width, height and depth.

CHAPTER 1

INTRODUCTION

1.1 Introduction.

Mining survey tasks fall into two main categories; the practical control of material movement and the collection of spatial data of physical surfaces. The current technology used by the surveyor to undertake both of these tasks consist of traditional theodilite surveys and RTK GPS surveys, involving a field party of one or two people.

Surveying in a large open cut mining operation exposes survey staff to interactions with heavy mining equipment as well as placing them in confined work areas with unstable high and low walls. As a result of working under these conditions, data can be sparse and traditional methods of survey are both time and labour intensive.

1.2 Research Objectives.

This project will look at the use of a terrestrial laser scanner in an open cut coal mining environment for the application of collecting spatial data of physical surfaces only. Such surveys include:

- Post blast surveys.
- Dragline extraction surveys.
- Face shovels surveys.
- Coal stockpile surveys.
- Lowwall monitoring.
- Accident Surveys.
- Coal floor pickups for the purpose of generating mine working plans.

The project will also examine whether a TLS complies with the NSW Coal Mine and Survey drafting directions for order of accuracy for mining surveys and provide a cost benefit analysis over traditional survey practices currently undertaken at the mine.

1.3 Study Area.

Mount Thorley Warkworth mine is situated 2.5 hours north of Sydney and 1 hour west of the port of Newcastle.

Figure 1.1 Aerial Photo – Site Location (Courtesy of Google Maps).

The current mine operations cover an area of approximately 48 km² and employs in excess of 1000 people. The mine produces 9.2 million tonne of saleable coal per annum and has an overburden operation of 92 million tonne per annum making it the largest multi-seam coal mine in the hunter valley and one of the largest in Australia. The mining fleet consists of three electric draglines, three electric face shovels, four hydraulic excavators, fifty six haul trucks, as well as other auxiliary loading units and earthmoving equipment. Dragline and face shovels are due to complete 24 and 28 passes respectively, which as well as exposing coal, involve the construction of complex ramping and rehabilitation systems that require strict survey control to avoid costly mistakes.

Figure 1.2 Aerial Photo – Site Location (Courtesy of Google Maps).

In comparison the MTW survey team is relatively small, with only three permanent surveyors, plus a rotational graduate who is present for only six months of the year. A strong case currently exists for an additional surveyor to achieve the appropriate level of service required to sustain the current needs of the operation let alone any future increases in productivity. This project highlights the benefits which a TLS can make in the open cut mining environment with respect to employment of another full time surveyor, as well as the cost benefits a TLS can provide to the company.

1.4 Dissertation Structure.

The aim of this project is to examine the use of a TLS in an open cut mining environment. This was achieved by performing the following:

- Identifying mine surveys suitable for using a TLS.
- Identify which areas of government legislation apply to the use of coal mining surveys and equipment.
- Undertake and compare surveys utilising the TLS and current mining survey methods.
- Compare time taken to undertake surveys using a TLS and current mining survey methods.
- Analyses cost savings with regards to payback time for the acquisition of a TLS.

1.5 Conclusions: Chapter 1.

This research aims to identify the uses of a terrestrial laser scanner in an open cut mining environment and cost savings associated with its use. The results of this project will form the basis for the justification of the purchase of a TLS for Mount Thorley Warkworth mine and other Rio Tinto operations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

In the introduction chapter of this dissertation, we were introduced to the research objectives along with the area of study and the structure in which the dissertation will be written.

The purpose of this chapter is to give a definition of what is a laser scanner, along with the principles of how a TLS works and the application of TLS's in general surveying and more specifically, mining surveying. This chapter will examine the government legislation governing the use of TLS's for mining and look at some traditional survey techniques versus scanning.

2.2 What is a Terrestrial Laser Scanner?

As defined by BÖhler and Marbs (2002), a laser scanner uses laser light to measure distances from the sensor to the object in a systematic pattern. Laser scanning uses a reflectorless electronic distance measuring device (EDM) coupled with automatic rotation of a range finder to measure individual points in an arbitrary Cartesian coordinate system.

The two main types of laser scanning include terrestrial and airborne. As the names suggest, airborne laser scanning is conducted from an aircraft usually for the purposes of mapping large scale areas of land. Terrestrial laser scanning is conducted from the land surface to measure objects of a smaller scale, to a higher accuracy. There are a range of commercially available terrestrial laser scanners on the market each with their own specifications and accuracies. As a general rule their acquisition speeds are incredibly rapid, 4000-500,000 points per second, not necessarily sacrificing accuracy for speed. However the higher scan rates are often clarified as a maximum instantaneous boost, of up to ten times the nominal speed. Likewise the capable range also varies greatly between models, from 80m – 700m but, unlike the speed, there seems to be a clear degradation in accuracies when range capabilities are increased. (Leica 2007, iSite 2007, Riegl 2007)

2.3 Principles of a Laser Scanner.

Laser scanners fall into one of three categories with respect to their ability to measure distance between the sensor system and target. Fröhlich, (2004) summarises laser scanner classification, based measurement technology, range, accuracy and manufacture, as can be seen below in table 2.1.

Measurement Technology	Range (m)	Accuracy (mm)	Manufacturers
Time of flight	<100	<10	Callielus, Leica, Mensi, Optech, Riegl
	<1000	<20	Optech, Riegl
Pulse phased	<100	<10	IQSun, Leica, VisImage, Zoller + Frohlich
Optical Triangulation	<5	<1	Mensi, Minolta

Table 2.1 Classification of Laser Scanners.
Source: Fröhlich, C.; Mettenleiter, M. (2004)

2.3.1 Time of Flight Scanners.

For large ranges, the time of flight (TOF) method of measurement is used to calculate the distance from the sensor to the object. As with reflectorless EDM, it is a simple calculation based on the following formula.

$$D = \frac{ct}{2}$$

Where D is the distance, t is time and c is the speed of light. Figure 2.1 displays the principles of a pulse laser range, using the TOF method of calculation.

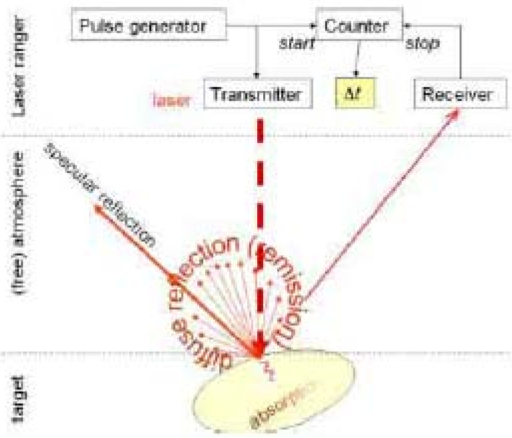


Figure 2.1 Principle of Pulse Laser Ranging.
Source: Norbert Pfeifer, Christian Briese (2007).

TOF accuracy depends on the ability to accurately measure time, and the accuracy of the system to detect "backscatter", Norbert and Briese (2007). Jutzi and Stilla (2005) have devised echo detection algorithms for post processing which allows for the phenomenon of backscattering to be reduced from TOF calculations. The I-Site LR4400 laser scanner which was used in the evaluation for this project is an example of a TOF scanner, as shown in Figure 2.2.

Figure 2.2 I-Site LR4400 TOF Scanner.
Source: http://www.maptek.com/

2.3.2 Phase Based Scanners.

In order to obtain higher precision and higher measurement rates, Phase Based measurement technology has been applied to terrestrial laser scanners. This consists of using a continuous wave laser to carry an amplitude modulated signal. The phases of the emitted and received signals are compared and the number of full wavelengths between the sensor and reflecting object counted. Given the known wavelength, point distance can be derived using the following formula:

$$\boldsymbol{r} = \Delta\varphi/(2\lambda)\ \lambda/2 + \lambda/2n,$$

Where $\Delta\varphi$ is given in radians, λ is the known wavelength and n is the number of whole wavelengths. Norbert and Briese (2007) provide an example of modulated wavelengths and carrier wave for pulse phase based laser ranging.

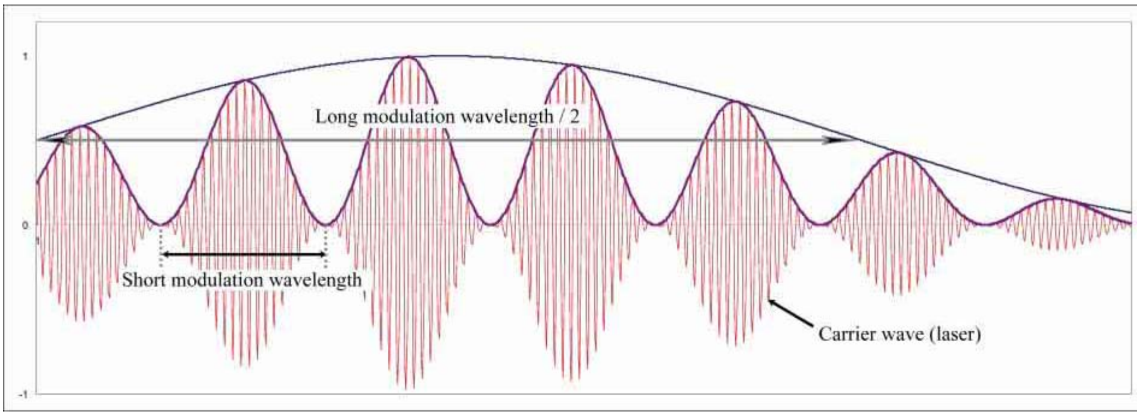


Figure 2.3 Schematic Drawing of two Modulated Wavelengths and Carrier Wave for Phase Based Laser Ranging.
Source: Norbert Pfeifer, Christian Briese (2007).

Figure 2.4 Leica HDS6100 Phase Based Scanner.
Source: http://www.leica-geosystems.us.

2.3.3 Triangulation Scanners.

Triangulation scanning determines range via angular measurement as opposed to distance measuring, and as a result has the highest precision of all the measurement technologies found in laser scanners. They were among the first scanners to be developed by the National Research Council of Canada in 1978 and use a laser plane as opposed to a laser beam to interrogate surface features.

The principles involved in triangulation scanning are similar to the principles found in photogrametry, where matching point pairs form intersecting planes are triangulated to give a unique position of any one surface feature. A more in depth explanation of the triangulation method can be found with Beraldin (2000), but the below Figure 3.5 shows the basic principle of the triangulation measurement technology.

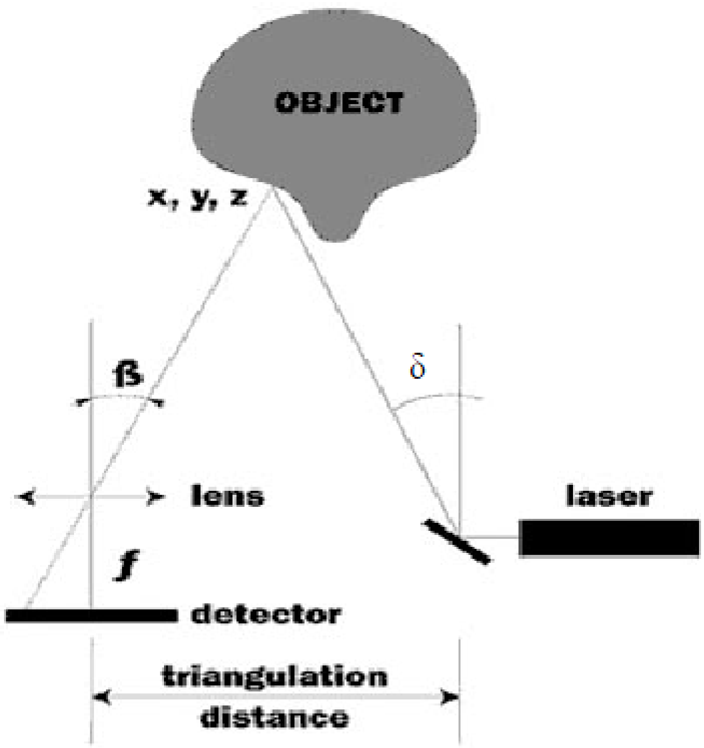


Figure 2.5 3D Laser Triangulation.
Source: http://wwwinition.co.uk.

2.4 Application of the Laser Scanner.

2.4.1 Application – General.

Applications for the use of TLS systems in the surveying arena are wide and varied. There application in day to day surveying is only limited by the users confidence and understanding of its principles and achievable accuracy of the TLS system and software. Spatial Resources (2009), lists just some of the areas in which TLS's are making inroads in the world of spatial measurement. These include:

- Civil engineering, Transportation and Surveying.
- Construction.
- Forensics.
- As-builts.

2.4.2 Application – Mining.

This dissertation is based on the application of the TLS in an open cut mining environment and there have been many case studies undertaken of its use and achievable accuracies therein. Maptek (2009) lists several case studies for the use of terrestrial laser scanner in:

- Open cut mining.
- Underground mining.
- Stockpile and geological mapping.
- Stockpile and volumetric surveys.

The underlying theme in these case studies is that the use of a TLS system provides a fast and economical way of capturing vast quantities of spatial data. The TLS survey can be undertaken from a location outside any existing hazards due to its range and speed of capture, which increases the factor of safety for its users.

Specific examples of the use of a TLS system in the mining environment can be found further on in this dissertation.

2.5 Legislation governing the use of Laser Scanners for Mining.

The use of TLS systems in the mining environment fall under three pieces of government legislation for use in NSW when being used for the purposes for locating mine workings which will be shown on the mine workings plan. The first piece of legislation is the Survey and Drafting Directions for Mine Surveyors 2007, (NSW – Coal). This document sets out the accuracies that must be obtained to show mine workings on the mine workings plan. Clause 3.33 states:

3.3.3 Secondary surveys shall be employed by the Mining Surveyor where necessary to accurately locate all of the Mine workings on the Mine Workings Plan to within 1mm at 1:2000 Scale. Such surveys shall be completed to the highest appropriate standards of accuracy.

The above accuracy equates to a spatial position of ±2m. Today's TLS systems easily achieve the accuracies set out in S&DD 2007 and as such would make a prime candidate for their application in the open cut mining environment.

The second piece of government regulation governing the use of TLS systems in open cut coal mining in NSW is the Coal Mine Health and Safety Regulation 2006. Division 1, Controlled Materials, Plant and Practices, Subdivision 1, Note 71 makes reference to Australian Standard 2397 – 1993. Standard 2397-1993 refers to the safe use of lasers in the building and construction industry and sets out the safety requirements for the use of lasers for alignment, levelling, control and survey tasks, (AS2397-1993). This standard also set out the procedures of use pertaining to each laser class. As the majority of TLS systems available today use Class 1 to Class 3A lasers, no special operational procedures need to be followed for there use.

The third piece of government regulation governing the use of TLS systems in open cut coal mining in NSW is the Surveying Regulation 2006. This document does not regulate the use of a TLS in mining, but sets out the conditions to which a TLS's electronic measurement device must adhere to in order to have legal traceability of measurement for a given survey. Division 3, clause 14 states:

Equipment for measurement of surveys

(1) A survey must be made using appropriate equipment.

(2) A surveyor must not use any equipment in making a survey unless the surveyor knows the accuracy obtained by its use. That accuracy must be determined by reference to:

(a) the Australian primary standard of measurement of length, within the meaning of the National Measurement Act 1960 of the Commonwealth, or

(b) the State primary standard of measurement of length, within the meaning of that Act, that is under the control of the Surveyor-General,

(4) A surveyor must not use any electronic distance measuring equipment in making a survey unless it is verified against the State primary standard of measurement of length (as referred to above), by using pillared testlines, at least once every year and immediately after any service or repair.

(6) The accuracy and method of any verification under this clause must be as approved.

A TLS system differs in the way they measure point data, i.e. they cannot be pointed directly at a target. A TLS's range is also less than that of a surveying total station which when combined makes them unsuitable for use on the state pillared base line as required for measurement validation by the Surveying Regulation 2006.

2.6 Conclusions: Chapter 2.

This chapter looked at the different types of TLS measurement technology available in the market place. From the literature review, it would show that a TOF TLS would be most suited for the mining environment as range is preferred over accuracy.

The application of the TLS is becoming increasingly vast as surveyors expand their knowledge of the technology and apply these systems outside the bounds of traditional surveying techniques. An issue arises once we apply the regulations governing their use for certain mining applications, and as such will need to be limited in use to areas that don't require legal traceability of measurement.

CHAPTER 3

RESEARCH, DESIGN AND METHODOLOGY

3.1 Introduction.

In the literature review chapter of this dissertation, the principles behind the TLS system where discussed, along with the application of TLS's in the day to day surveying environment, then focusing more specifically on the application of the TLS in the mining environment and how the use of a TLS system interacts with current government and mining legislation regulating its use.

The purpose of this chapter is to give an overview of three types of TLS systems that are under consideration for purchase, and examine the different mining surveys suitable for its use. As the mining environment for testing and subsequent use is a large scale open cut coal operation, preference was given to scanners with long range capabilities, along with functionality to include geo-referenced imagery. Accuracy could be in the order of 1 – 5cm as this would be deemed suitable for the majority of mining applications.

This chapter also looks at the survey processors involved with data capture and the problems encountered both in the field and office. As with any new technology, the surveyor must have confidence that the data being collected complies with the stated instrument accuracy, and that the data allows for sufficient redundancy against gross errors.

3.2 Equipment.

3.2.1 Product comparison.

The three brands of instruments evaluated as part of the TLS validation are the I-Site 4400LR, the Riegl and Laser Ace. The I-Site LR4400 TLS is a TOF, pulsed rangefinder scanner, as shown in Figure 3.1. It is able to acquire data at a rate of 4400 points per second and has a range up to 700m depending on surface reflectivity. The stated single point accuracy in ideal operation is ±20mm and a repeatability of ±10mm. The manufacture however states that its range under normal field use is ±50mm for single point accuracy and an increase of accuracy of repeatability of 50mm / √the number of scans taken. The accuracy and range of this TLS is adequate for mining operations at MTW as an increase in accuracy does not lead to any appreciable increase in material volume and any extension in range would lead to a decrease in the angle of incidence of the laser, and as a result would reduce the accuracy of the data captured.

The I-Site LR4400 has an in-built 37 megapixel digital camera for photo geo-referencing and post processing software called "I-Site Studio", which allows for quick and easy data registration and manipulation. The technical specification can be found in Appendix B.

Figure 3.1 Image showing the setup of the I-Site LR4400 scanner.

The Riegl TLS is a TOF scanner as show in Figure 3.2. It is able to capture data at a rate of 11000 points per second and has a stated range up to 1000m depending on surface reflectivity. The extended range of this scanner over the I-Site LR4400 is of no real benefit to the MTW operations, due to the reasons cited above in the I-Site LR4400. The Riegl has a stated accuracy of ±8mm with a repeatability of ±4mm and comes with an ad-on 12.3 megapixel digital camera for photo geo-referencing.

The Riegl system also came with “I-Site Studio” post processing software for data registration and processing. The technical specification can be found in Appendix B.

Figure 3.2 Image showing the setup of the Riegl scanner.
Source: http://www.riegl.com/

The Laser Ace TLS is a TOF scanner as shown in figure 3.3. It is able to capture data at a rate of 250 points per second and has a range up to 700m depending on surface reflectivity. The Laser Ace TLS does not have the facility to geo-reference images like the Riegl and I-Site.

The Laser Ace system comes with “Laser Cloud Viewer” and “Laser Cloud Modeller” software for registration and processing of captured data. The technical specification can be found in Appendix B.

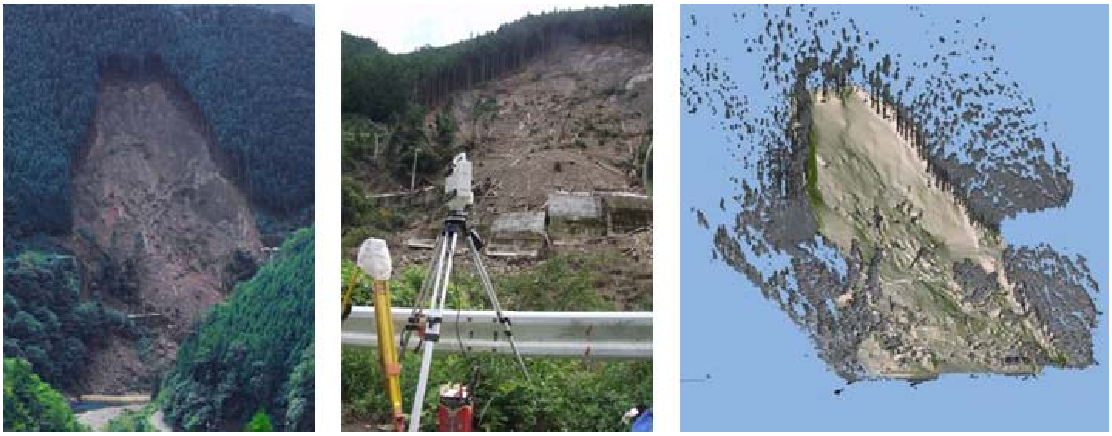


Figure 3.3 Image showing the setup of the Laser Ace scanner and triangulation.
Source: http://www.mdlaustralia.com.au

Table 3.1, summarizes the main comparisons between the three TLS systems which were evaluated as part of this dissertation. All instruments located the same data source and range was based on measuring to a combination of black coal and grey sandstone surfaces.

Product	Total Cost of Package	Demonstrate Range at MTW (m)	Total Equipment Weight (kg)	Use Friendliness/ Portability	Software Package details	Maintenance Agreement Details	Setup and Operation Time	Manufacture and Service Location
I-SiTE	$217,750	550m	16kg	Battery, camera and scanner one unit. Dedicated control screen separate unit.	Supplied with tailored I-SiTE Studio software. Able to manipulate, reduce and align data. Able to export to other design packages.	Replacement machine provided during servicing. $17,500 per annum covers all servicing, software support, calibration and upgrades.	Setup time similar to current survey equipment. Scanning time averaged 10 minutes for detailed 360 degree scan with photo.	Adelaide, Australia
Riegl	$297,000	600m, limited by angle of reflectance	26kg	Heavy and awkward to carry and setup. 3 cables required to be connected for each setup. Laptop, battery and camera separate components.	Very similar to I-SiTE, in fact can be supplied with the same software.	Replacement machine provided during servicing. No other details supplied	Setup time slower than current survey equipment due to additional cables and separate components. Requires back-sites to data.	No details supplied.
Laser-Ace	$58,000	250m	8kg	Light and easy to carry. Simple and easy to use.	Data downloaded to conventional design packages directly.	No details supplied	Setup time similar to current survey equipment. Slow to scan large area's - would provide limited advantage over current survey equipment.	No details supplied.

Table 3.1 Comparison results of the three tested TLS’s.

3.3 Survey Examples.

3.3.1 Survey Types.

The typical types of surveys undertaken with the TLS include the following:

- Accident surveys.

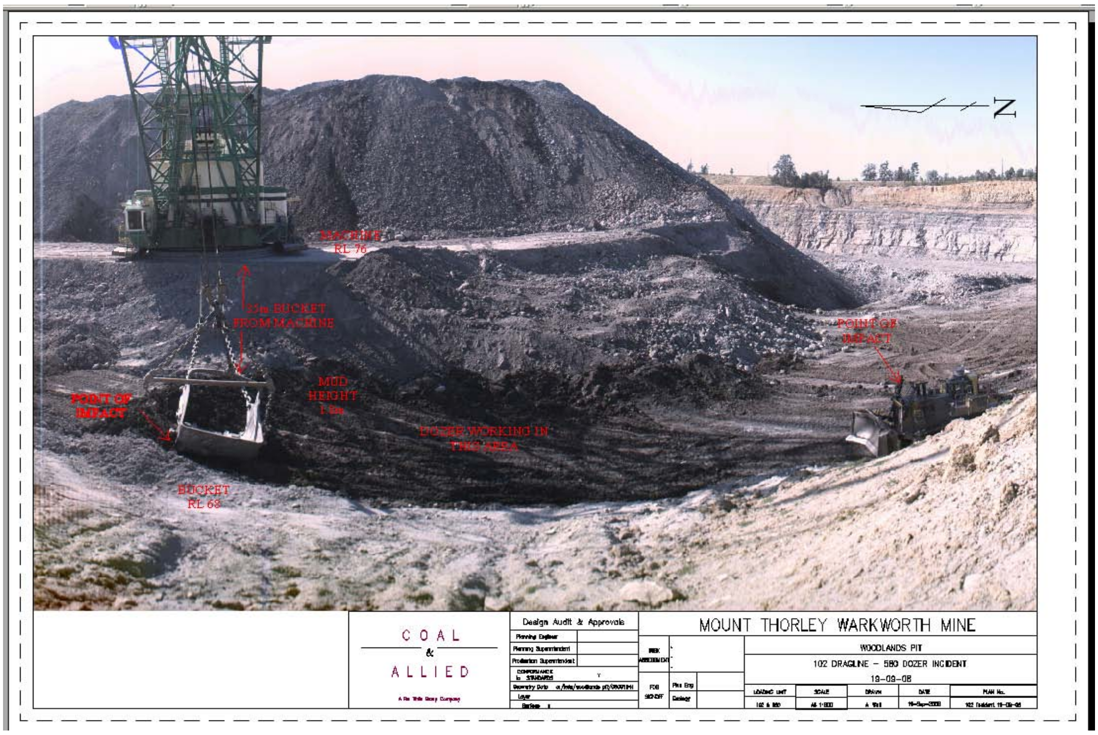


Figure 3.4 Geo-referenced image of a dragline/ dozer interaction.

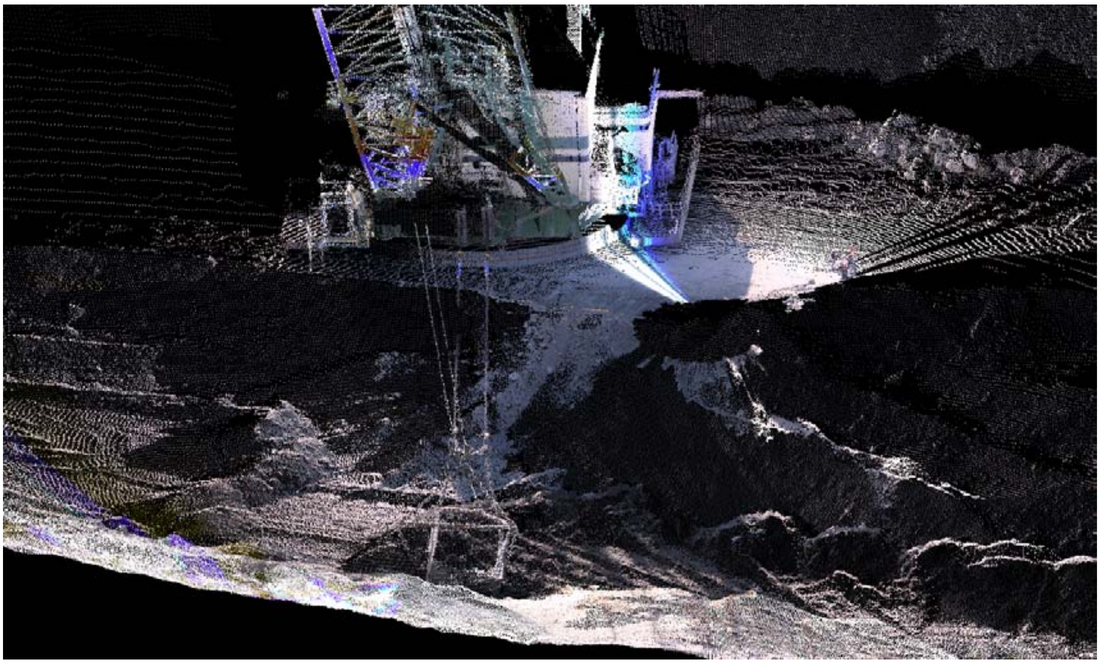


Figure 3.5 Point cloud data of Figure 3.4.

- End of month volume surveys.

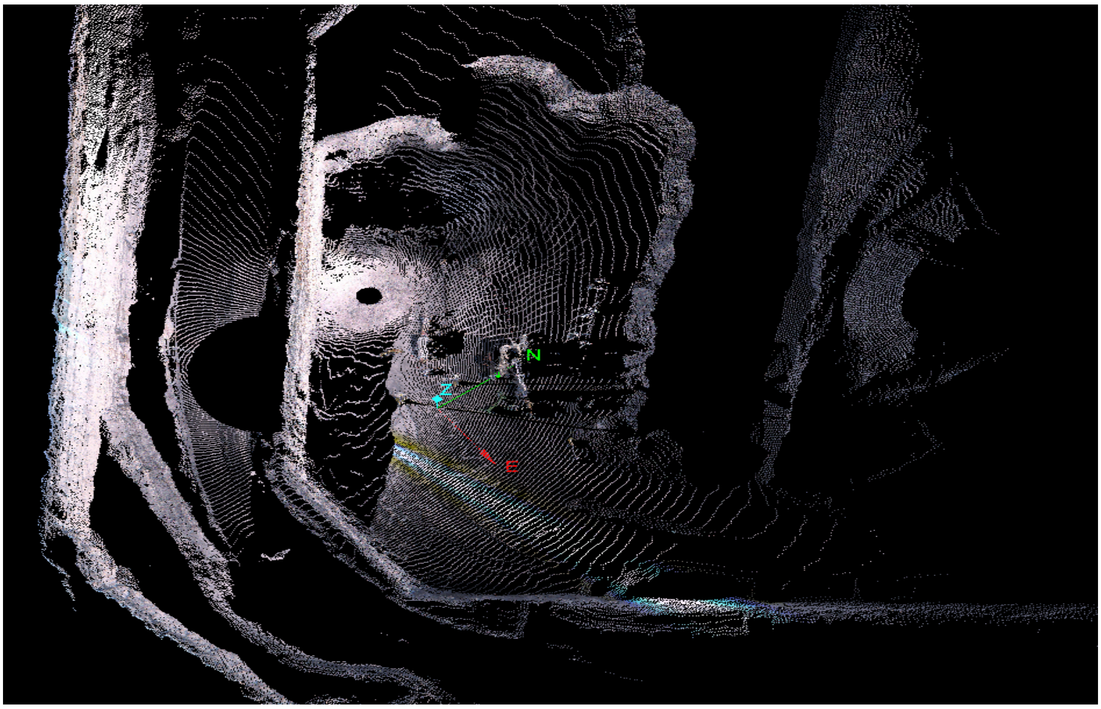


Figure 3.6 Point cloud data of an End of Month shovel dig.

- As mined coal floor pickups.

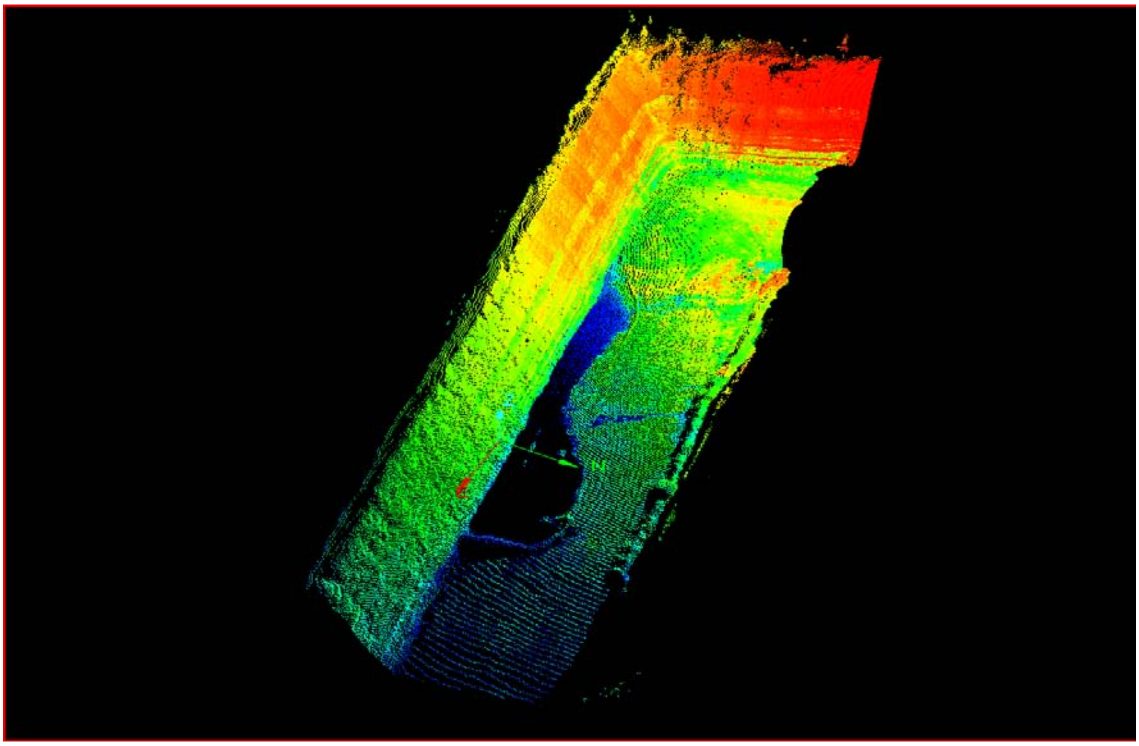


Figure 3.7 Survey of Coal floor extraction areas for Digital Record Tracings.

- Coal stockpile surveys.

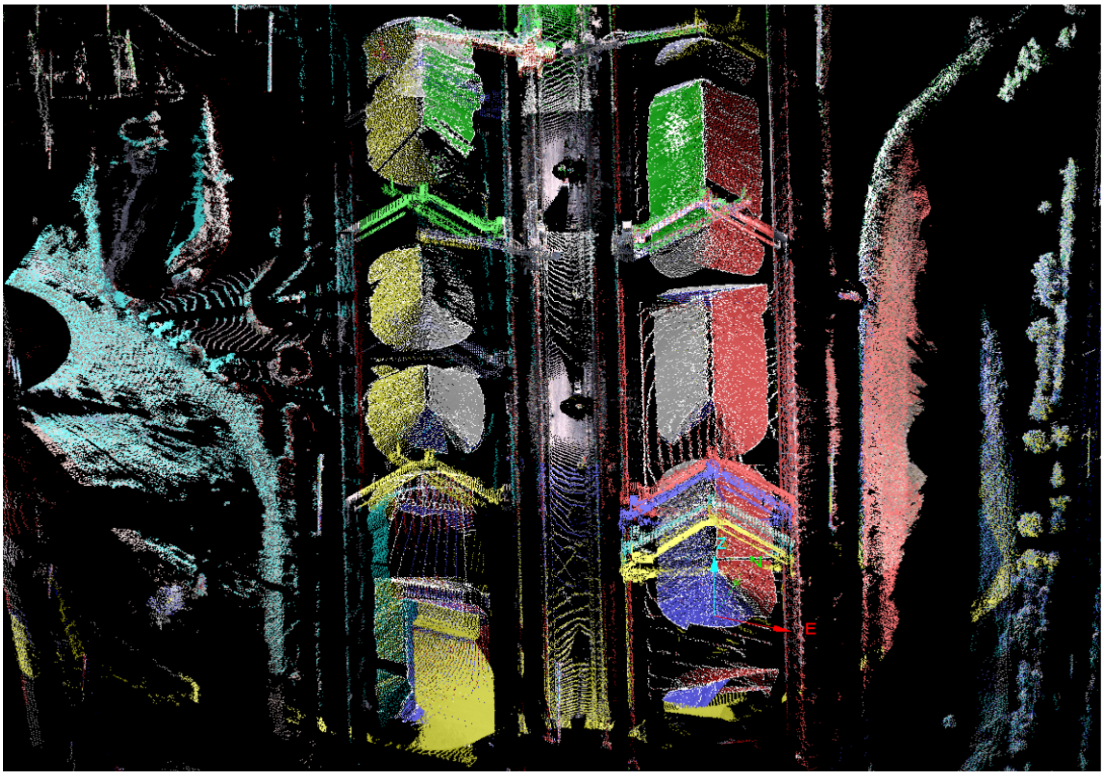


Figure 3.8 Point cloud data of MTW north clean coal Stockpiles.

- Coal seam mapping.

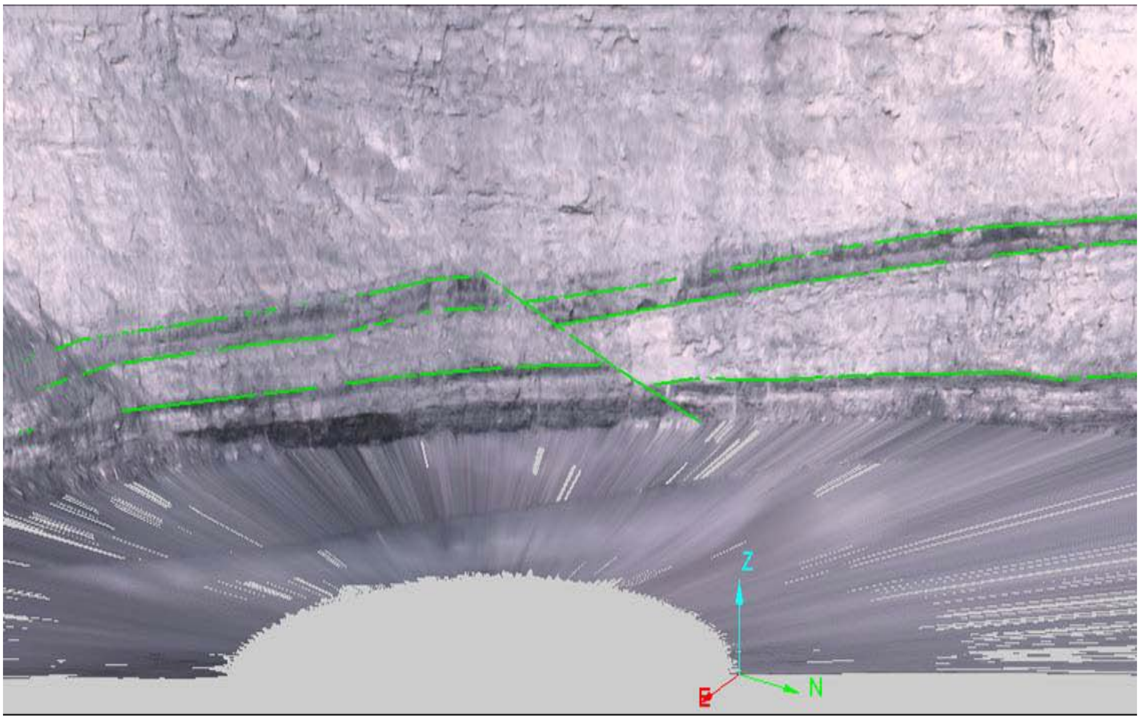


Figure 3.9 Survey of Coal Seam Mapping from TLS data and geo-referenced photo.

- Stability monitoring.

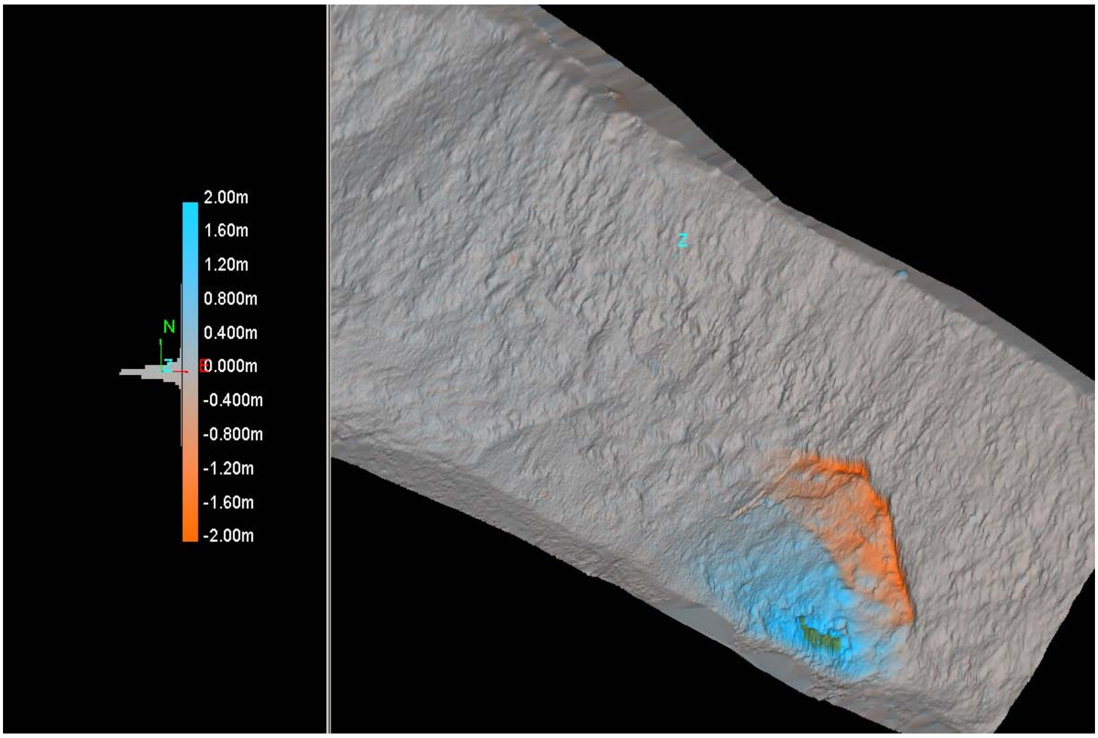


Figure 3.10 Survey of lowwall stability monitoring.

- Tailings dam surveys.

Figure 3.11 Geo-referenced image of tailings dam survey.

- Truck factor studies.

- DTM updates.

- Pre and post blast surveys.

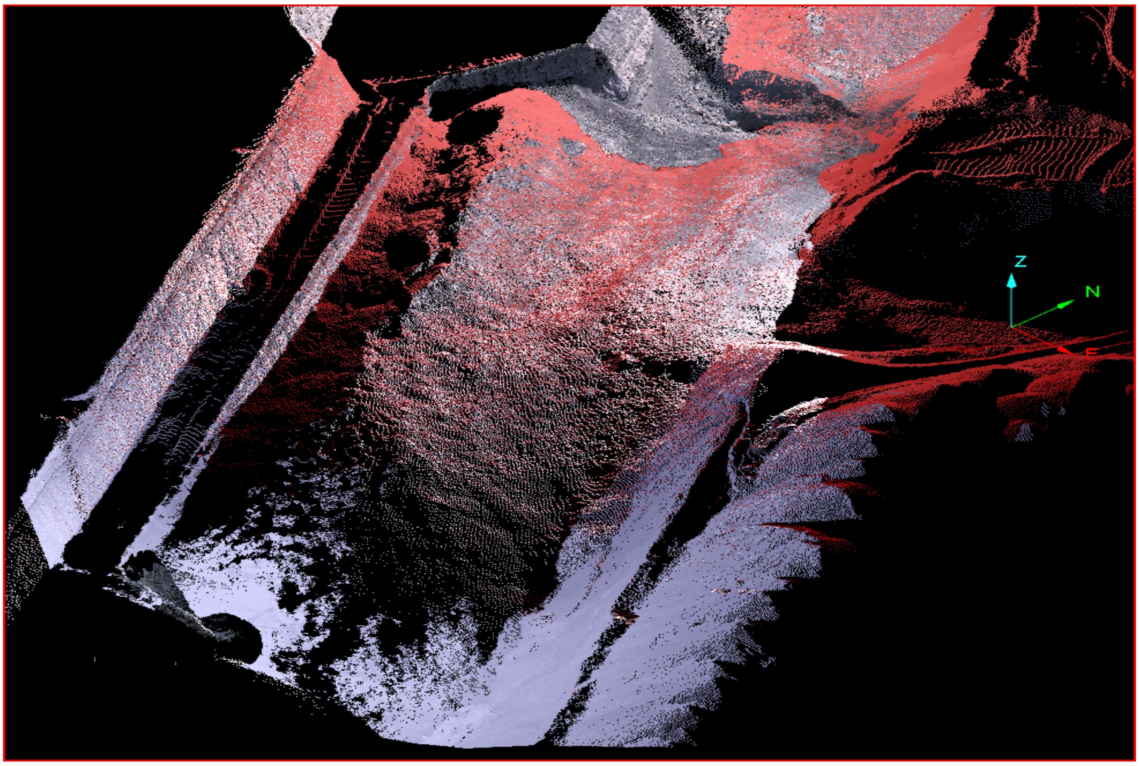


Figure 3.12 Point cloud data of post blast survey.

Figure 3.4 to 3.12 illustrates the type of data collected by the I-Site terrestrial laser scanner of the above surveys. The ability to be able to quickly and efficiently capture mass amount of spatial data over a large area with the I-Site system allows for greater accuracy in volume calculation and complex modelling of wall structure which can be hard if not impossible to obtain with traditional survey techniques.

3.3.2 Survey Process.

The below Figure 3.13 is a flow chart of the processor involved for undertaking a scan with the I-Site TLS.

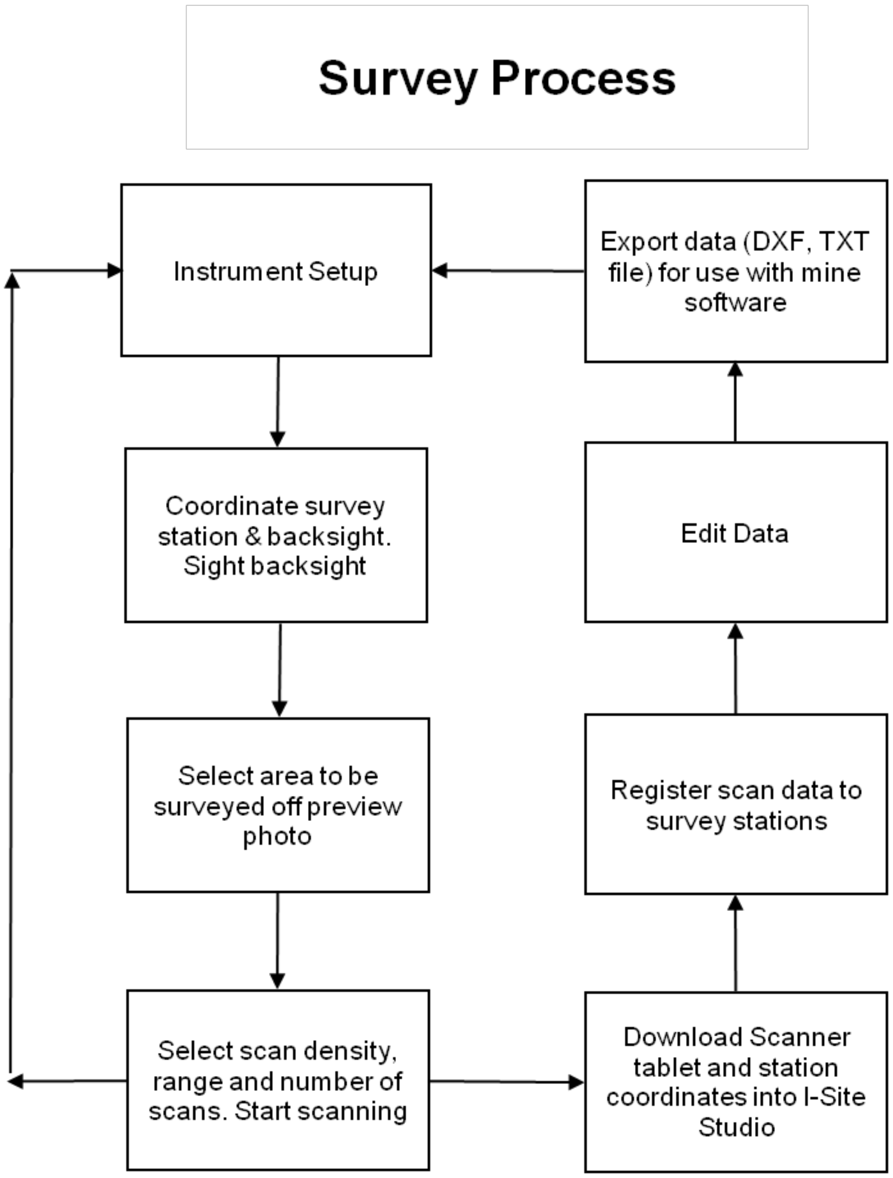


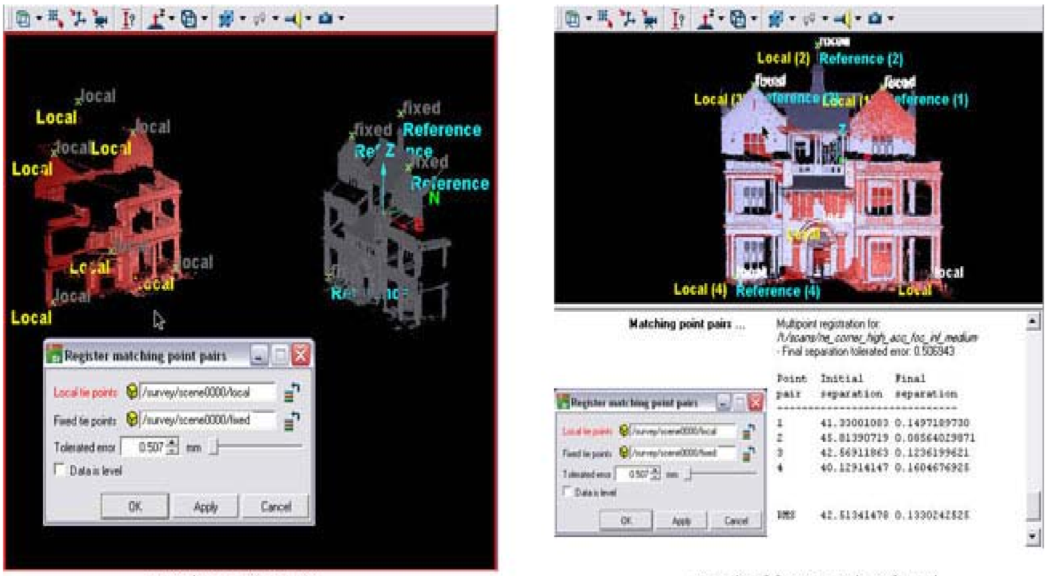
Figure 3.13 Flow chart of the survey process

3.3.3 Raw Data Processing.

In order for the user to be able to get useful information from the vast amount of point cloud data obtained by the TLS system, a successful registration must be performed on the data to firstly align the scans with each other, then secondly to orientate and translate the scans to a coordinate system for correct spatial orientation.

There are several ways in which this can be achieved through I-Site Studio. These include:

- **Matching Point Pairs.** This option is used to position any type of data using the best fit between groups of local and reference points and where there are common features visible. Figure 3.14 shows how Matching Point Pairs is achieved.



Matching point pairs. Result of four matches found.

Figure 3.14 Image showing matching point pairs.
Source: Maptek I-Site Studio reference manual

The final RMS of 0.133m after registration is an indication of how well all of the scan data matched, not an indication of the spatial precision of the data. The Final RMS could be reduced by selecting more point pairs for surface matching.

- **Matching Surface Features.** Matching Surface features is used once scans have been registered close together using scanner position or matching point pairs. There must be sufficient data overlap for this function to operate. Whereas matching point pairs referenced scans through pairs of corresponding points, matching surface features allows for scans with an overlap area of data to be referenced together. The software essentially finds mass amounts of common points in the overlap areas to perform the registration.

- **Matching to Survey Datum.** This function is used where there is a coordinated station and backsight. As with traditional survey data reduction, the scan data is registered simply by translation and rotation commonly found in all survey software. It should be noted that the above two registration techniques allow for only one position scanning position to be known, and all subsequent scans, providing there is sufficient data overlap, can be translated and rotated to for one unique data set.

The comparison of matching point pairs and matching surface features to traditional survey techniques is outside the scope of this dissertation, but would provide an area of further study.

3.4 Problems.

3.4.1 Field Issues.

Using any new or unfamiliar technology can pose problems to the user if not thoroughly trained in its operational principles. The I-Site LR4400 although easy to use, displayed unreliable characteristics when used under certain situations. These included:

- **Dust.** Measuring in light to medium dust, which is a common environment in mining applications, causes the laser to measure the dust particles as well as measuring the desired object. The dust particles show's up as "noise" on the scan when processed, but can easily be removed in the editing stage. Heavy dust should be avoided as this will provide no return of the laser signal. See figure 3.15. Dust "noise" can be minimised through scanning up-wind of the subject site, or through planning of the data acquisition for a suitable time.

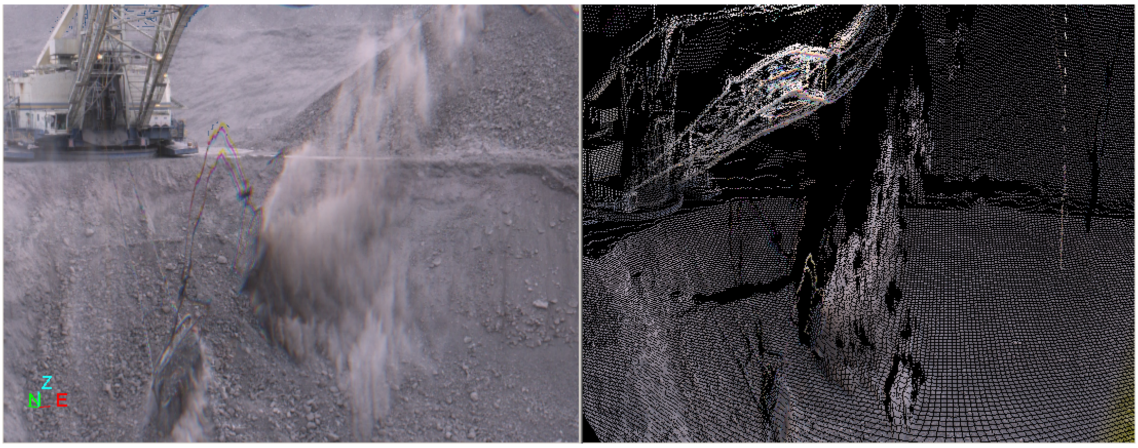


Figure 3.14 Survey showing dust noise.

- **Rain.** Measuring in rain has similar results to measuring in dust. Light to medium rain causes "noise" to appear on the scan when processed. As is the case with dust, rain "noise" is easily removed by the I-Site Studio software and heavy rain should be avoided.

- **Water.** Measuring through a water body other then rain, has mixed effects on the data capture. Measuring through clear water causes the laser to distort when travelling through the water medium, thus returning points lower then what they would be if no water is present. Turbid water causes the laser to reflect off the surface, thus creating a flat area and misrepresenting what is actually under the surface. Although no in depth analysis was undertaken in this area, these findings were observed from several different scans and water body types. See Figure 3.16.

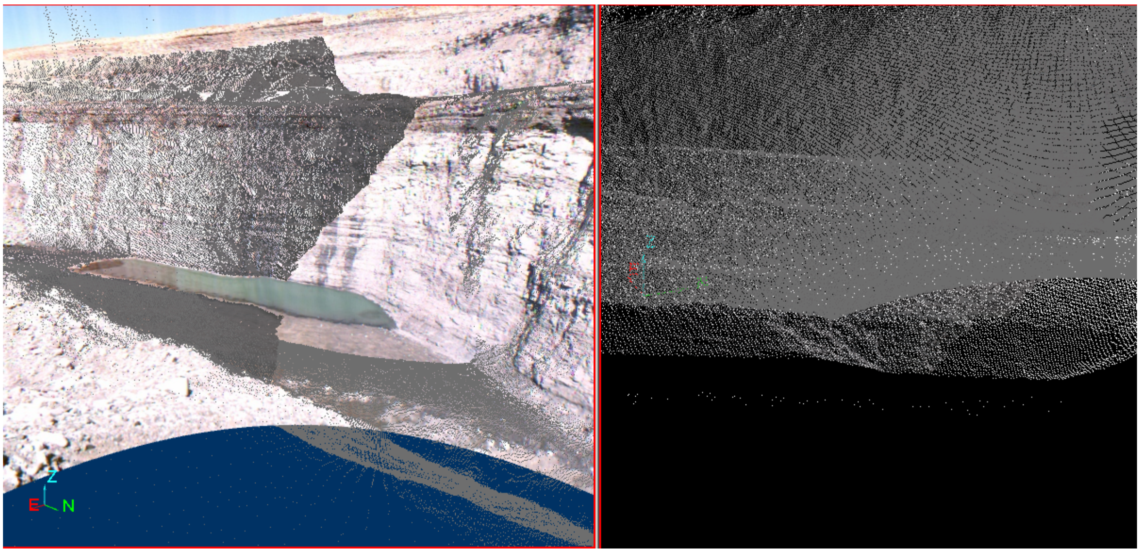


Figure 3.16 Survey showing effects of water.

Other field issues that arose from using the scanner, but not associated with operational principles included:

- **Weight.** The I-Site scanner weighs 16 kilograms with the battery, so careful setup selection is needed to avoid carrying the heavy weight to far over uneven ground.

- **Batteries.** The onboard battery is capable of only 12 hi resolution scans.

- **Camera.** Light intensity settings need to be manually inputted before scan is started, if you wish to digitise data off the geo-referenced image. The light intensity can be changed after the preview scan has been taken and before the scan starts, if the wrong light intensity has been selected.

- **Setup.** Careful selection of the setup site must be made, as losing a $227,000 scanner over a highwall or lowwall is costly.

- **Availability.** Due to the high workload of the survey team at MTW and the readily availability of survey data through the use of the TLS, time management of the use I-Site TLS was necessary.

3.4.2 Office Issues.

As with the issues encountered with the use of the TLS in field operation, similarly, office issues were encountered which were mainly due to the inability of other mine packages to handle the vast amount of survey data captured during the scanning session. These issues included:

- **Data Filtering.** Due to the large amount of survey points collected in the survey, data needed to be filtered so as it could be used in other mining packages. It was found that data had to be filtered down by a scale of 1.5 times to be able to be efficiently used in Minescape, and filtered down by a factor of 0.5 to be able to be used in Minex, without sacrificing software performance in the two packages.

- **Data Structure.** Since an increase in workflow can be achieved through the use of a TLS system, thought must be given to the efficient storage structure of raw and processed data. The collected data needs to be able to be archived and located to be used by the surveyor and other third parties. A disorganised data structure would lead to data being lost or not used, and this would result in wasted survey hours.

3.5 Conclusions: Chapter 3.

A comprehensive market assessment of laser scanning products was undertaken in preparation for this dissertation. As a result, three products were chosen for demonstration on site. The results are summarised in Table 3.1.

The Laser Ace scanner, although by far the cheapest, did not have the required range or ability to collect and process large amounts of data of the other two scanners. It did not represent a significant time saving or advantage over current survey equipment at MTW. Its application is more suited to small quarries or civil applications.

The Riegl scanner had the largest range of the three scanners and had similar capture and processing ability of the I-Site laser. Scanning range though is limited by the angle of reflectivity and therefore the additional range would not translate to a tangible saving in time. The unit was heavier and cumbersome in comparison to the I-Site scanner.

The accuracy achieved by both the Laser Ace and Riegl scanners out performed that of the I-Site scanner, but for the majority of mining applications, the accuracy of the I-Site laser was more than sufficient. For these reasons and others outlined in Table 3.1, the I-Site LR4400 laser scanner was deemed to be the most suited to MTW of the three products reviewed.

The issues experience both in the field and in the office would be similar to all of the TLS systems trialled at MTW, due to similar operation of all three systems, and the large amount of spatial data being collected. Further study however should be undertaken using different laser types to see their effect on water and dust.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction.

In the research, design and methodology chapter of this dissertation, examples of work undertaken by a TLS were examined, as well as the issues arisen from data collection and manipulation. An evaluation was undertaken of three TLS systems deemed suitable for use in a large open cut environment with the I-Site LR4400 being the preferred TLS system

The purpose of this chapter is to examine the cost and physical benefits achieved through the use of an I-Site system, and provide analysis of the pay back time for the purchase of a TLS over employing another full-time surveyor.

4.2 Cost Analysis.

4.2.1 Increase in Cast to Final.

Information collected through the TLS will increase overburden material cast to a final position during blasting operations. In order to comply with environmental license conditions a generally conservative approach is adopted when designing face holes in blasts. Currently face hole are positioned in relation to the designed location of the presplit. Highwall faces are represented by crest and toe surveys and only major anomalies in the face are surveyed using traditional reflectorless theodilites.

The improvement in fragmentation and percentage throw would be realised if face holes were designed based on detailed face profiles. This involves positioning individual holes based on the required burden at that location. On board drill GPS allows holes to be drilled accurately as designed.

Detailed profiling using the TLS allows optimised face hole locations. This translates into a 2% improvement in throw quantities, based on removing burdens of 0.5m above design on 30% of face holes. A corresponding reduction of 87,000 bcm of dragline volume enables a cost saving of $48,000 per annum

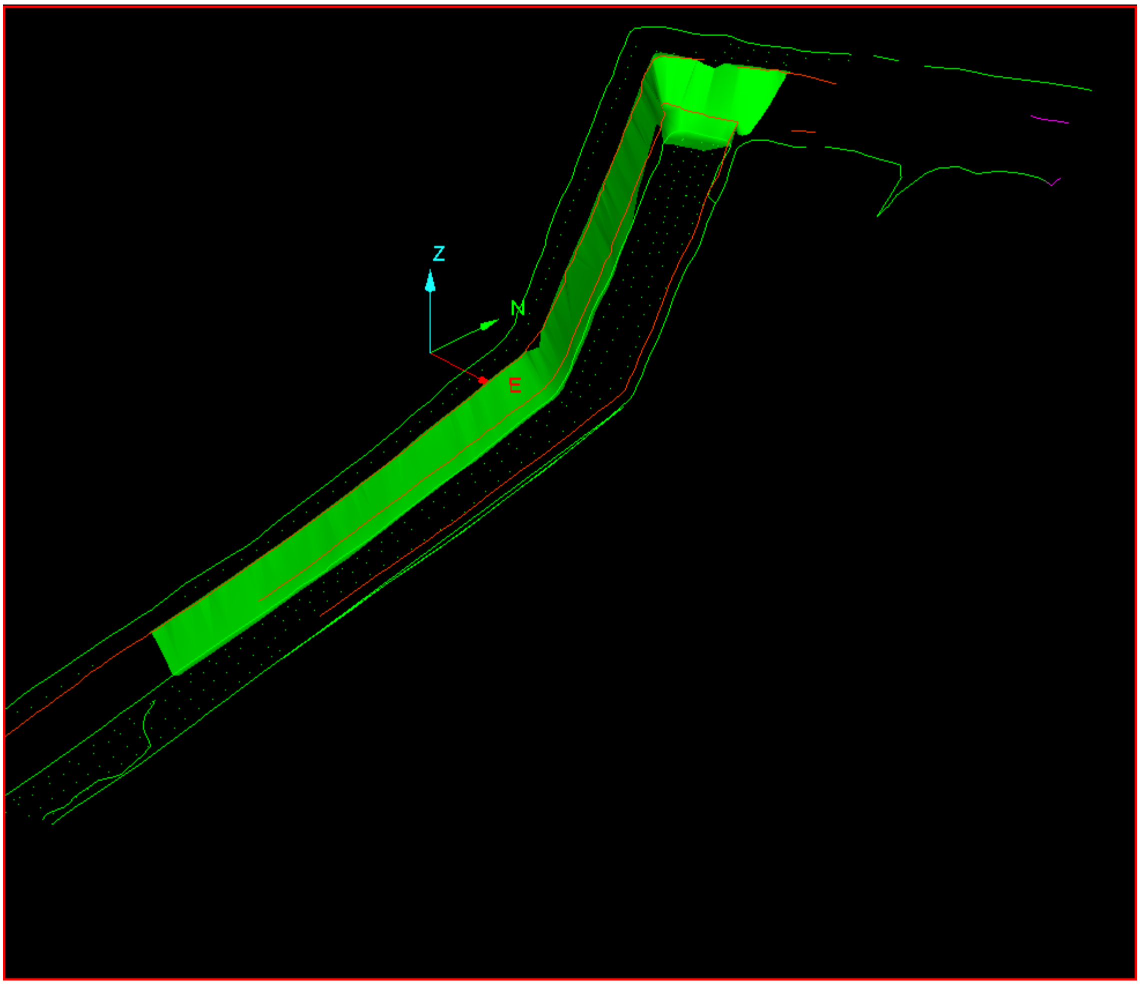


Figure 4.1 Example of GPS data of highwall survey.

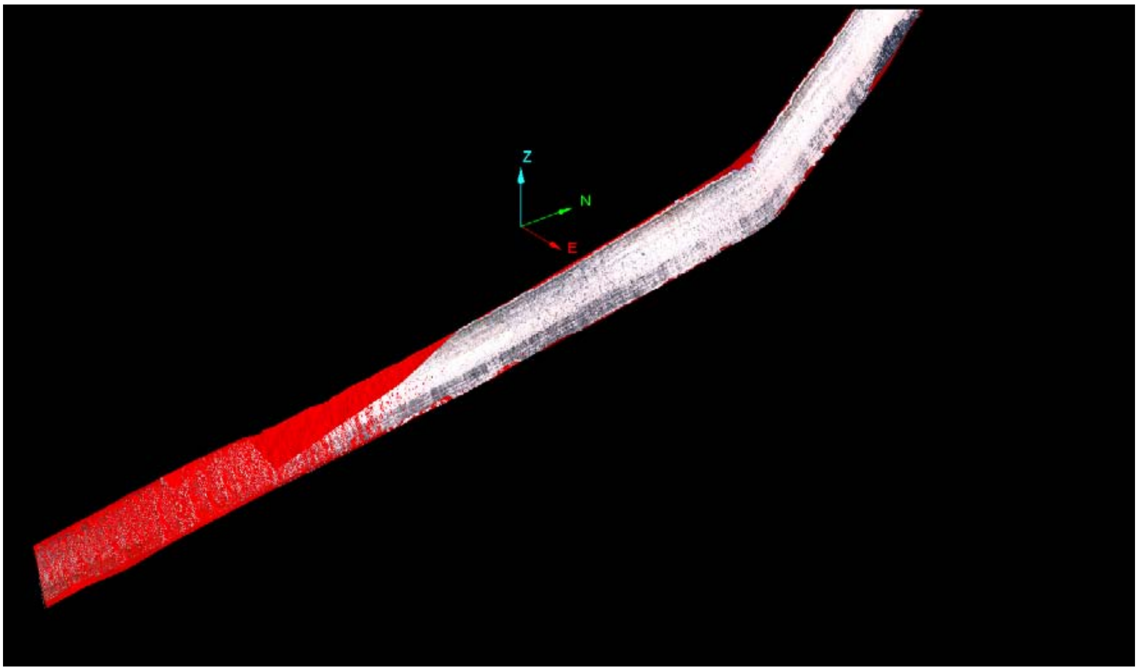


Figure 4.2 Example of I-Site data of highwall survey.

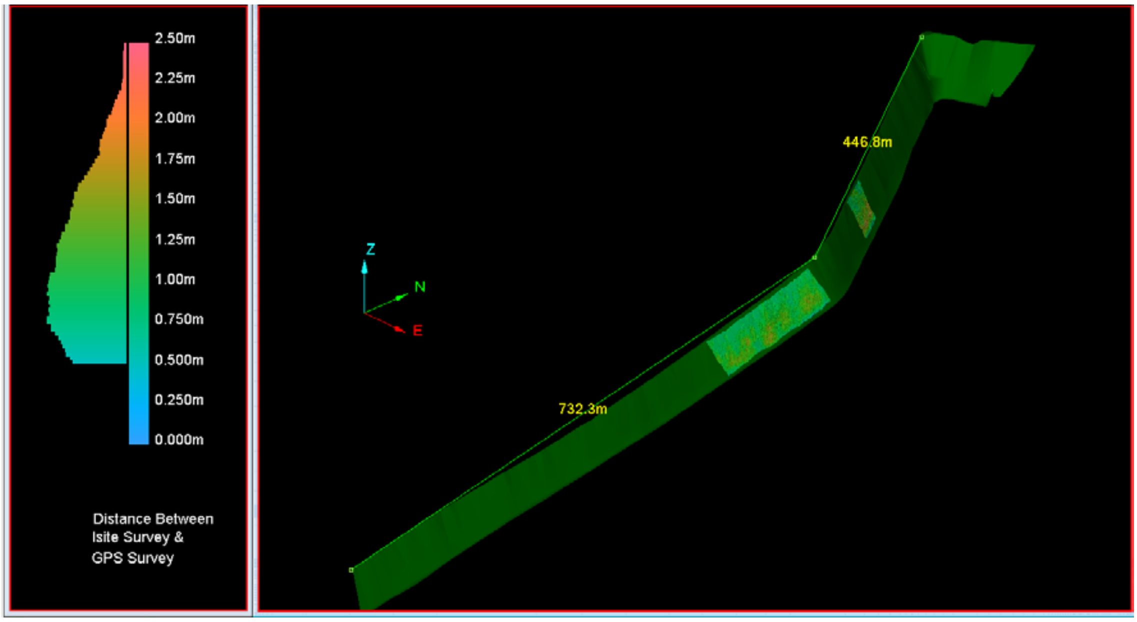


Figure 4.3 Histogram showing distance between I-site survey & GPS survey.

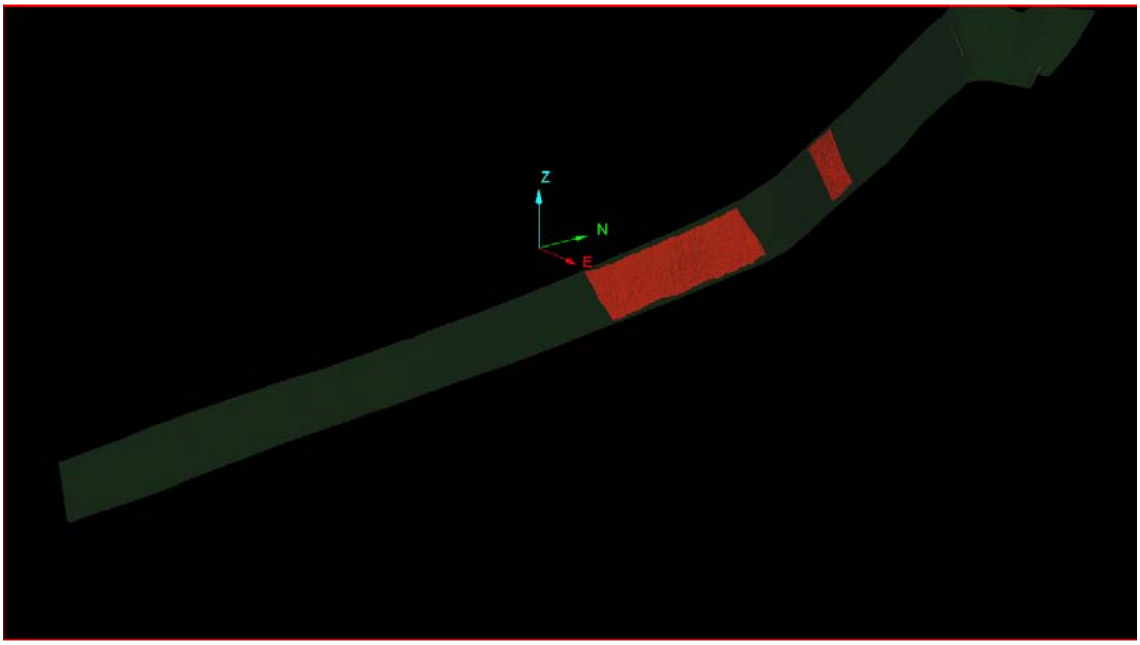


Figure 4.4 Areas where distance between I-site survey & GPS survey vary by >0.5m.

Figure 4.3 is a histogram depicting the areas between the GPS survey and I-Site survey where the difference in face burden is greater than 0.5m. Refer to Appendix D. The face burden in these areas would be reduced to provide maximum throw blast.

4.2.2 End of Month Stockpile Surveys.

At the end of each month and where directed, coal stockpile surveys are currently performed by a field party of two contract surveyors. With the increase efficiencies through the use of a TLS and the ability to quickly survey large stockpiles, this process can be performed by the site surveyors resulting in a direct saving of $48,000 per annum. Refer to figure 3.8

4.2.3 Additional Surveyor.

As outlined in sectioned 4.3.1, a strong case exists for the addition of one more surveyor to the survey team, along with additional survey equipment, the purchase of TLS technology will allow the appropriate level of survey service to be reached with the current survey team numbers. On personnel alone disregarding new equipment purchase, this will avoid an additional cost of $119,000 per annum.

4.3 Benefit Analysis.

4.3.1 Survey Team Benefits.

MTW is a relatively large scale, complex and high output mine. Its three draglines and three rope shovels are due to complete 24 and 28 passes respectively in 2009. Dragline passes are relatively complex with lowwall ramps, centre ramps, Jensen and Curtis, extended keys large changes in elevation, 35m wide coal trenches, 50m high lowwalls and spoil dumps common place. Its three shovels also report to a large number of dumps that tie into a complex rehabilitation system. The processes require strict survey support include drilling, blast profiling, rehabilitation, coal and parting and statutory requirements.

In comparison the MTW survey team is relatively small, with only three permanent surveyors, plus a rotational graduate surveyor for only six months of the year. As supported in appendix 3, a strong case currently exists for an additional surveyor to achieve the appropriate level of service required. The total additional work hours calculated to achieve the required output is 1,612hours per annum. A full time surveyor is able to complete 1,800 hrs per annum.

TLS technology has enabled the appropriate level of service to be achieved with the current size of the survey team. As shown in Appendix C, the total additional time to achieve the same required output with TLS technology is only 397 hours. This additional time can be achieved through the application of TLS technology to existing services supplied by the surveying team. This is due to the large area of data that can be collected and processed quickly using TLS technology. Figure 4.5 is an example of information that was collected from two survey points at MTW. This data was collected and processed in 2 hours. In comparison with traditional survey techniques at MTW, it would take around 8 hours, multiple setup locations and traversing on foot to collect and process only a fraction of the amount of information gathered by the TLS.

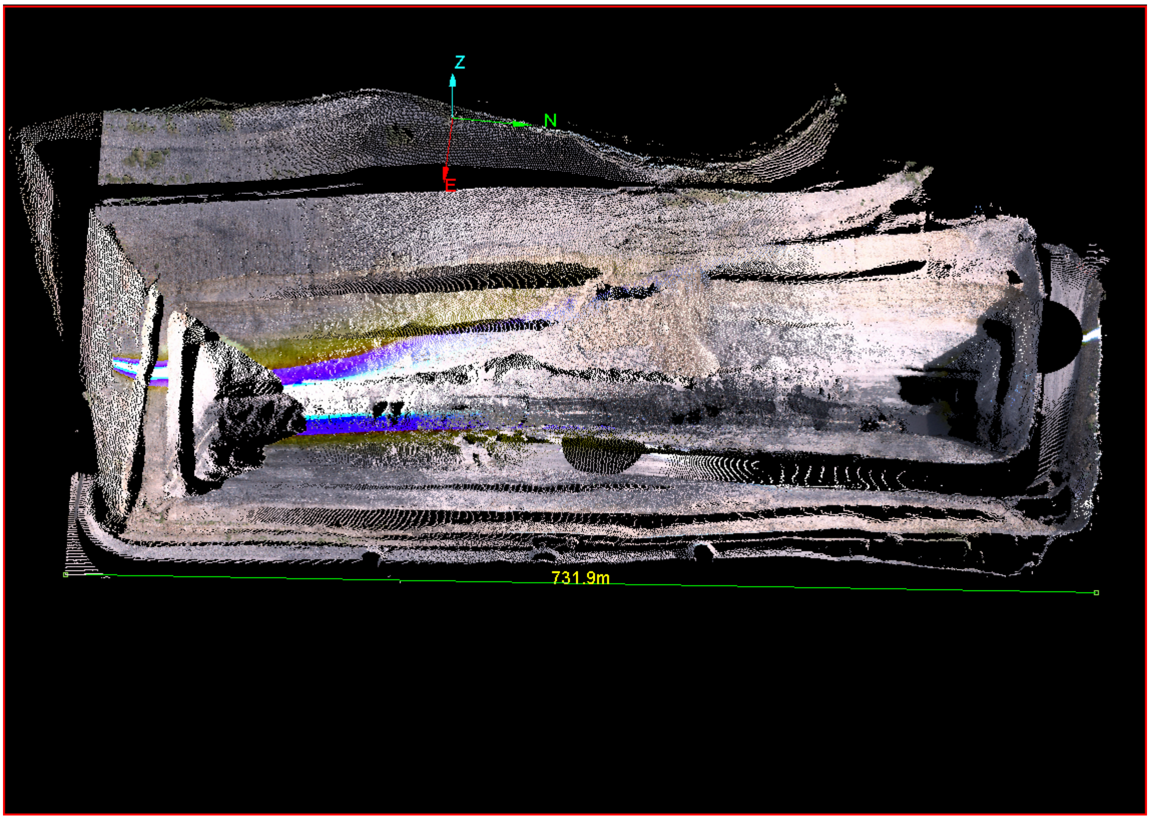


Figure 4.5 Example of TLS data located from 2 survey stations.

4.3.2 Mine Design Improvements.

TLS technology has enabled more accurate, more detailed and timely acquisition of "as dug" surfaces, allowing surveyors to maintain an up to date topographic model. This has a significant flow-on benefit to design engineers, who currently construct their own 'as dug' surfaces prior to beginning a design. More time is available for option analysis to reach an optimised final design.

As entire mine surfaces are now routinely surveyed, as opposed to crests and toes only, designs will become more accurate. A greater understanding of spoil characteristics will enable more accurate dragline designs, potentially increasing coal recovery and decreasing re-handled material.

4.3.3 Geotechnical and Geological Understanding.

TLS technology enables geological and geotechnical data to be routinely collected simultaneously with regular survey data. This consists of 3-Dimensional data with a photographic image geo-referenced. This can be processed in a significantly reduced timeframe compared to using the current sirovision technology. The flow-on benefits would be;

- A comprehensive geotechnical survey of each Highwall.
- A more accurate geological model as more seam horizons will be mapped and data processed faster.
- The geological team will have more time for other tasks, as they no longer need to collect the information TLS technology can collect as part of routine surveys.

Refer to Figure 3.9

4.3.4 Other Potential Benefits.

Other additional benefits for the utilisation of a TLS system include;

- A reduction in oversize material in the free face area of face shovels blasts by placing the front row of holes closer to the free face.
- Reduced risk of face burst and consequential environmental harm or equipment damage via an improved understanding of face profiles.
- Reduced chances of surveyor re-work by not retrieving the right field data.
- An improved understanding of cast blast performance and profile characteristics for input into mine designs.
- Payload analysis can be performed in both rear dump trucks and buckets.
- Reduced reliance on contract surveyors for coverage during annual leave periods.

4.4 NPV Results and Sensitivity Analysis

As outlined in section 4.2, there are three tangible financial benefits realised through the purchase of TLS technology:

1. Increased cast to final volume, annual saving of $60,900.
2. EOM coal stockpile surveys performed in-house, annual saving $48,000.
3. Negate the need for an additional surveyor, annual saving of $119,000.

Two scenarios were analysed, firstly with all three benefits realised and then secondly if only benefits 1) and 2) were realised. See Appendix E for a full analysis. The outcomes are outlined in the table below.

Scenario	Benefits Realised	Total Annual Savings	NPV (8%)	Payback Period
1	Cast to final increase. In-house EOM coal stockpile surveys. No additional surveyor.	$227,900	$466,564	1 year
2	Cast to final increase. In-house EOM coal stockpile surveys.	$108,900	$121,179	2.1 year

Table 4.1 Results of NPV (8%) and sensitivity analysis.

4.5 Conclusions: Chapter 4.

The purpose of this chapter is to examine the cost and physical benefits achieved through the use of a TLS, and provide analysis of the pay back time for the purchase of a TLS over employing another full-time surveyor. The purchase of a TLS in particular the I-Site laser scanner and software will provide annual savings of $227,900, with an NPV (8%) of $466,000 and payback period of 1 year. The savings occur in increased cast to final, in-house end of month stockpile surveys and the saving of an additional surveyor. This is primarily achieved through the ability of TLS technology to collect and process vast amounts of data, including photographic images, in a fraction of the time of conventional survey methods. The photographic ability of the TLS technology makes it a very cost effective geology/ Geotechnical instrument as well, enabling wall scans with joint and boundary mapping information.

If the saving of an additional surveyor is not included in the financial calculations, the annual cost savings are reduced to $108,900, with an NPV (8%) of $121,800 and payback period of 2.1 years

CHAPTER 5

CONCLUSIONS, DISCUSSION AND IMPLICATIONS

5.1 Introduction.

The aim of this project arose from the need to develop new ways of incorporating survey technology into the open cut mining environment which not only increased surveyor safety, but enabled the current survey team at MTW to meet the current mining operation demands with less reliance on increasing survey staff numbers.

This dissertation was therefore designed to evaluate the use of a terrestrial laser scanner in an open cut mining environment, and to assess its value within the MTW survey team, along with determining whether or not use of a TLS would meet current government legislation governing its use in an open cut coal environment.

5.2 Discussion.

Mining survey tasks fall into two main categories; the practical control of material movement and the collection of spatial data of physical surfaces. The collection of spatial information has been the basis of surveying for near its inception. Being able to quickly and accurately determine the position of an object relative to another, or being able to reference the object to a common coordinate system is what we as mining surveyors try to achieve on a daily basis.

Through the advancement in measurement technology, TLS systems are taking common place in the surveyors arsenal of measuring equipment, and as such, need to be evaluated for not only there cost saving benefits, but also how they can reduce surveyor workload. This dissertation identifies both of the above benefits which leads the writer to conclude that the acquisition of a TLS system for the surveyors at MTW is a viable and valuable purchase. All of the survey types identified in Chapter 3 can be competently undertaking with the use of a TLS system with the exception of surveys used for the preparation of statutory mine working plans. It should be noted that a TLS system meets the accuracies set down by the relevant government legislation with respect to surveys undertaken to prepare statutory mine working plans, but lacks official traceability in measurement as there is no calibration test site to verify a TLS system against the "*state primary standard of measurement of length*".

5.3 Further Research and Recommendations.

This dissertation examined the practical application of a TLS system for the open cut mining operations at MTW, and the costs benefits applicable to its use. The dissertation however did not directly compare tried and tested traditional survey results against the results obtained through the use of a TLS system. Large amounts of data exists which confirms manufactures claims of the TLS system, but as yet, there is no formal government documentation for a calibration technique that allows a surveyor using a TLS system to meet the guidelines set down by the Surveying Regulation 2006 in NSW which state that "*A surveyor must not use any equipment in making a survey unless the surveyor knows the accuracy obtained by its use. That accuracy must be determined by reference to:*

(a) the Australian primary standard of measurement of length, within the meaning of the National Measurement Act 1960 of the

Commonwealth, or

(b) the State primary standard of measurement of length, within the meaning of that Act, that is under the control of the Surveyor-General".

Further research in this area would be beneficial to all surveyors working in NSW so as surveyors can continue to keep pace with technology and ultimately reduce the surveyor's physical workload in certain environments.

Appendix A

PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: ***ADRIAN WALL***

TOPIC: *THE USE OF A TERRESTRIAL LASER SCANNER IN THE MINING ENVIRONMENT*

SUPERVISOR: *Zhenyu Zhang*

PROJECT AIM: *This project will look at the use of a terrestrial laser scanner in an open cut coal mining environment and examine whether it complies with the NSW Coal Mine and Survey Drafting Directions for order of accuracy of mining surveys.*

PROGRAMME: ***Issue A, 24th March 2009***

1. *Give an overview of the use of the terrestrial laser scanner in the open cut coal mine operation.*
2. *Identify which section of legislation deals with survey accuracy and instrument verification for mining surveys.*
3. *Analyse results obtained and determine if results comply with survey accuracies.*
4. *Develop a calibration procedure for compliance with relevant survey legislation if time permits.*
5. *Submit an academic dissertation on the research.*

AGREED:

________________ *(student)* ________________ *(supervisor)*

_____/_____/_____ _____/_____/_____

Examiner: ____

Appendix B

PRODUCT SPECIFICATION DATASHEET

MAPTEK™ I-Site™ 4400LR

Terrestrial Laser Scanning System

The Maptek I-Site™ 4400LR is an advanced multi-sensor laser scanner with a range of up to 700 metres. I-Site scanners include a high precision alignment telescope, digital tilt compensator and built-in panoramic digital camera, and are integrated with standard survey work flow and external data such as GPS. The system is sold with all software, support, maintenance and training included.

SYSTEM INCLUDES

- I-Site 4400LR laser scanner and accessories
- I-Site Studio processing and modelling software
- Windows™ style data browser
- Training and installation
- Support, maintenance and training

- Range up to 700 metres
- Dedicated field hand-held controller, no external laptop required
- Built-in survey grade alignment telescope for backsighting
- 80° vertical and 360° horizontal field of view
- Removable long lasting NiMH battery pack
- Used in vertical or horizontal stand point. Ideal for scanning in silos, sheds etc
- Built-in high accuracy tilt compensator to ensure scans are levelled correctly
- Rapid registration of multiple setups gives greater coverage than other long range scanners from one setup
- 37 megapixel inbuilt panoramic digital camera. Image texturing is automatic, requires no user calibration or alignment
- Distinguish features not always visible in intensity of scan points
- High resolution digitising directly from the image in 3D

Hand Held Controller Features

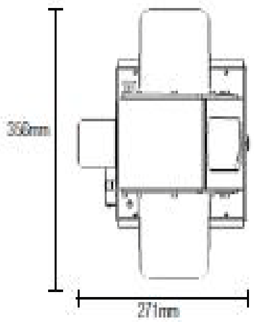
- Panoramic colour preview image
- Select scan extents from preview image
- Query scanner status and battery power
- Control scan resolution
- Control panoramic camera image exposure settings
- Automatic multiple scan averaging
- Manage scans through explorer with preview swatches
- Store and apply survey control from many sites for automatically coordinated scan data
- Enter instrument height
- Fast USB transfer to workstation
- Intuitive scan naming
- All-visible indoor/outdoor option (direct sunlight readable)

System Package

- I-Site 4400LR laser scanner and operating accessories
- I-Site Studio software tools for registration, processing, modelling and export
- Training and installation conducted on-site or in our offices
- Hardware and software maintenance program includes upgrades, servicing, calibration and certification of the hardware and software for the first 12 months

Technical Specifications

DIMENSIONAL DRAWINGS



General

Type	Terrestrial laser scanner
Size	431 x 271 x 356mm
Weight	14kg (includes battery)
Battery	24VDC NiMH; interchangeable battery pack
Battery life	Approx 3 hours Standard battery; 6 hours optional HD battery
Levelling	Tilt compensator resolution: 20" (seconds)
Plate level bubble	30" divisions, 20' bulls-eye bubble
Temperature range	0 to +50°C [1]
	Short exposure -20 to +50°C [2]
Durability	Tested in accordance with AS 1099.2.27, 31
Protection class	IP-65 (dust and splash water proof)
Data Recorder	Via ethernet cable to I-Site HHC Tablet PC and software
Mounting	Standard tribrach mount included

Scanner

Type	Time of flight pulsed rangefinder
Wavelength	905nm
Beam divergence	1.4mrad
Maximum range [3]	200m to black coal (5-10% reflectivity)
	600m to rock/concrete (40-50% reflectivity)
	Up to 700m for higher reflectivity surfaces
Minimum range	5m
Range accuracy [4]	20mm
Repeatability [5]	10mm
Typical range accuracy [6]	50mm
Measurement rate	4400 points per second
Angular separation	Minimum 0.108°
Angular accuracy	+/- 0.04°
Angular scanning range	80° vertical, 360° horizontal
Laser class	3R laser product (IEC 60825-1)
Intensity measurement	Yes

Digital Camera

Type	Line scanning digital panoramic camera
Pixel resolution	37 megapixels
Angular range	80° vertical, 360° horizontal
Time	Acquired during laser scan
Exposure control	User definable
Lens	Nikon 20mm f/2.8D, with filter
Image render method	Corrected image is automatically rendered on scan surface
Depth of field	3m to infinity

Telescope

Angular range	Motorized control for 80° vertical and 360° horizontal
Focal range	5m to infinity
Focus control	Manual focus
Objective aperture	28mm
Magnification	14x
Reticle	Crosshair
Field of view	3 degrees in field (upright image)
Resolving power	+/-5"
Minimum azimuth step	20"
Laser pointer	650nm for survey alignment underground or in tunnels

[1] Heated batteries available on request for use in temperatures down to -40 degrees C
[2] Time to perform 10 minute scan
[3] Performance will vary depending on individual target surface characteristics
[4] Under I-Site laboratory conditions @ 50 metres
[5] Under I-Site laboratory conditions from averaged scans @ 50 metres
[6] Under general scanning conditions from 5 to 700 metres

Information accurate and reliable at time of printing

MAPTEK I-Site 4400LR

www.maptek.com

Technical Data 3D Scanner Hardware *RIEGL* LMS-Z420i

Laser Product Classification	Class 1 Laser Product according to IEC60825-1:2007 The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated July 26, 2001.

CLASS 1 LASER PRODUCT

Rangefinder Performance [1]

Max. Measurement Range [2]	
for natural targets, ρ ≥ 80 %	up to 1000 m
for natural targets, ρ ≥ 10 %	up to 350 m
Minimum Range	2 m
Accuracy [3,5]	10 mm
Repeatability [4,5]	8 mm (single shot), 4 mm (averaged)
Measurement Rate	up to 11000 pts/sec @ low scanning rate (oscillating mirror) up to 8000 pts/sec @ high scanning rate (rotating mirror)
Laser Wavelength	near infrared
Beam Divergence [6]	0.25 mrad

1) First, Last, or Alternating Target Mode selectable from scan line to scan line.
2) Typical values under average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter and near to perpendicular angle of incidence of the laserbeam. In bright sunlight, the operational range is considerably shorter than under an overcast sky.
3) Accuracy is the degree of conformity of a measured quantity to its actual (true) value.
4) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
5) One sigma @ 50 m range under RIEGL test conditions.
6) 0.25 mrad correspond to 25 mm increase of beamwidth per 100 m of range.

Scanner Performance

Vertical (Line) Scan	
Scan Angle Range	0° to 80°
Scanning Mechanism	rotating / oscillating mirror
Scan Speed	1 scan/sec to 20 scans/sec @ 80° scanning range
Angular Stepwidth Δ ϑ [7] between consecutive laser shots	0.004° ≤ Δ ϑ ≤ 0.2°
Angle Measurement Resolution	0.002°
Horizontal (Frame) Scan	
Scan Angle Range	0° to 360°
Scanning Mechanism	rotating optical head
Scan Speed [8]	0.01°/sec to 15°/sec
Angular Stepwidth Δ φ [7] between consecutive scan lines	0.004° ≤ Δ φ ≤ 0.75°
Angle Measurement Resolution	0.0025°
Inclination Sensors	optional, for vertical scanner setup position (specifications to be found in separate datasheet)
Internal Sync Timer	option for real-time synchronized time stamping of scan data (specifications to be found in separate datasheet)

7) Selectable via Ethernet interface or RS232.
8) Horizontal scan can be disabled, providing 2D-scanner operation.

General Technical Data

Interfaces: for configuration & data output	TCP/IP Ethernet, 10/100 MBit/sec
for configuration	RS 232, 19.2 kBd
for data output	ECP standard (enhanced capability port) parallel
Power Supply Input Voltage	12 - 28 V DC
Power Consumption	typ. 78 W — max. 94 W
Current Consumption @ 12 V DC	typ. 6.5 A — max. 7.8 A
@ 24 V DC	typ. 3.25 A — max. 3.9 A
Main Dimensions	463 mm x 210 mm (length x diameter)
Weight	16 kg
Temperature Range	0°C to +40°C (operation), -10°C to +50°C (storage)
Protection Class	IP64, dust and splash-proof

RIEGL LASER MEASUREMENT SYSTEMS

RIEGL Laser Measurement Systems GmbH, A-3580 Horn, Austria
Tel: +43-2982-4211, Fax: +43-2982-4210, E-mail: office@riegl.co.at
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RIEGL Japan Ltd., Tokyo 164-0013, Japan
Tel: +81-3-3382-7340, Fax: +81-3-3382-5843, E-mail: info@riegl-japan.co.jp

www.riegl.com

Data sheet, LMS-Z420i, 10/09/2009

LaserAce® Scanner

The LaserAce® Scanner is a new field instrument which combines reflectorless laser 'point and shoot' measurement technology and high speed laser scanning.

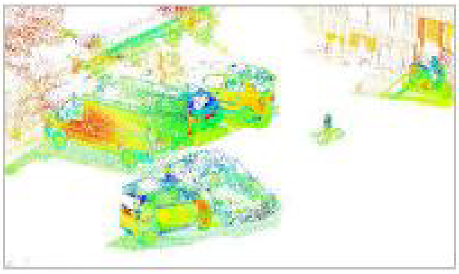
The result is an instrument, which can be used for both conventional 'Total Station' survey duties, such as traversing, intersection and resection **AND** '3D laser imaging'. Complete 'scenes' and objects in view at ranges up to 700 meters may be surveyed.

Up to 32Mbyte of data (3 million points) can be stored on an internal RAM card. External control via PC is also a standard option.

Power is 12V D.C.

Features

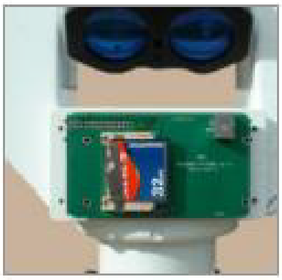
- 12 volt motorised stepper drives
- 360° x 130° continuous scanning area.
- Data and power slip rings for continuous operation
- External remote control optional.
- Highly portable and rugged device.
- Horizontal and Vertical clutch drive protection
- Internal Ram Card data logging 32Mbyte (3million points)
- Laser Class 1.
- Minimum step angle of 0.01 degrees.
- Rapid scanning up to 300 points per second.
- Red-dot pointing laser.
- Resolution of 0.01° in horizontal and vertical.
- Simple software for logging and display on PC.
- User defined coding system.
- User defined scan intervals.
- Variable scan speeds.
- Visible laser pointer Class 2.
- x 4 zoom sighting telescope.



Contact-less Laser Measurement of Buildings, Structures, Landscapes, Accident Scenes, Mining and Earth Moving Operations.

www.laserace.com

Red Dot
Pointing
Laser



Internal RAM
card (Under
access cover)

Applications

- 3D scene modelling and visualisation.
- Deformation surveys.
- Forensic scene, accident and crime scene surveys.
- As built surveys and street scenes
- Architectural and building conservation surveys.
- Earth works and volumetric calculations.

Laser Cloud Viewer (LCV) Software

- Processing of scan data into XYZ point cloud format.
- Export of data sets to 3rd party applications.
- Dynamic viewing and manipulation of data sets.
- Colour coded feature enhancement.

Laser Cloud Modeller (LCM) Software

- Triangulation of single surface scans.
- Rendering of surface by colour or grey scale.
- Dynamic contours, sections and dimensions from model.
- Calculation of volumes.

LASER MODULE	
Type	Semiconductor, 905nm
Accuracy, typically	10cm
Resolution	1cm
Range (LaserAce® 300)	350m
Range (LaserAce® 600)	700m
Glass Prism Reflector	5.0Km
LaserAce® 300	Class 1 CENELEC EN60825-1 (2001)
Pointer Option	Class 2 CENELEC EN60825-1 (2001)
LaserAce® 600	Class 1M CENELEC EN60825-1 (2001)
Pointer Option	Class 2M CENELEC EN60825-1 (2001)
KEYBOARD & DISPLAY	
Display	LCD
Lines/ Characters	4 x 20
Keyboard	Membrane Keypad
PHYSICAL DATA	
Construction	Machined Aluminium
Temperature Range	-10°C to +45°C
External Battery Pack	7Ah/ 12C DC

ANGLE	
Type	Opto Electronic Encoder
Accuracy	0.02°
Resolution	0.01°
Range	Vertical -45° to 90° Horizontal 0° to 360°
MOTION	
Stepper Driven Worm and Wheel Drives in both Axis with Manual Clutch Override System	
DATA LOGGING	
Links to	Laptop Computer, Desktop PC PDA Devices
Internal Memory	128Kbytes
Flash Card	32Mbytes
Water & Dust Resistant	IP66
Dimensions (LxWxH)	209 x 243 x 420mm
Weight	9.7kg (With Tribrach 10.2Kg)

Measurement Devices Ltd
Aberdeen Tel: +44 (0) 1224 246 700 * York: +44 (0) 1653 692 386
Houston, USA: +1 281 646 0050

LASER RADIATION
DO NOT VIEW DIRECTLY
WITH OPTICAL INSTRUMENTS
(MAGNIFIERS)
CLASS 1M LASER PRODUCT

LASER RADIATION
DO NOT STARE INTO BEAM
CLASS 2 LASER PRODUCT

Certificate No. Q 50061

Appendix C

SURVEYOR WORKLOAD

Design Implementation Action / Control Matrix - Actual Vs Design (Production and Planning)

- (red) Currently Not Performed due to lack of resources
- (orange) Only partially completed or performed infrequently
- (yellow) Should be performed by Surveying Team

Tasks	Accountable Person																	
	Operator		Supervisor		Surveyor		Additional Surveying time to fulfil requirement per annum		Engineer		Superintendent Production		Superintendent Planning		Manager Production		Manager Planning	
	Frequency	Action / Control	Frequency	Action / Control	Frequency	Action / Control	Without I-SiTE	With I-SiTE	Frequency	Action / Control	Frequency	Action / Control	Frequency	Action / Control	Frequency	Action / Control	Frequency	Action / Control
	Dragline																	
Dragline Key Dig																		
Check block progression	dig block	block markers	2 days	inspect area					3 x per week	view progress vs. block markers, use information in weekly plan update	weekly	inspect area	weekly	review in weekly planning meetings - compare progression to month plan				
Check Key width on coal	dig block	measure with disto, record onto checklist	2 days	View checklist, quiz operators							weekly	View checklist, discuss with supv and engineer						
Check Key crest vs. design / pegs	dig block	dig to pegs / clay targets	2 days	inspect area	weekly survey or on request	GPS, summary email to supv, supt and engineer	156	19.5	On exception	Assess impacts on design	weekly	inspect area	On exception	discuss as needed and review corrective actions	major exceptions	consulted during analysis / actions	major exceptions	provide direction for analysis / actions
Check batter angle	dig block	measure with smart tool, record onto checklist	2 days	View checklist, quiz operators							weekly	View checklist, discuss with supv and engineer						
Dragline Low Wall																		
Check block progression	dig block	block markers	Shiftly	inspect area	As D/L advances	Ensure block markers in in-place and visible to dragline operators	156	78	3 x per week	block markers	weekly	review in weekly planning meetings - compare progression to month plan	weekly	review in weekly planning meetings - compare progression to month plan				
Check LW crest vs. design / pegs	dig block	clay targets / ripper mark - line up with survey pegs	Shiftly	inspect area	Weekly	GPS, verbal advice to operator, e-mail report to superintendent and engineer. Tie in with bucket service	104	26			weekly	inspect area						
Check batter angle	dig block	measure with smart tool, record onto checklist	Shiftly	View checklist, quiz operators	Weekly	GPS, verbal advice to operator, e-mail report to superintendent and engineer. Tie in with bucket service	104	26	On exception	Assess impacts on design			On exception	discuss as needed and review corrective actions	major exceptions	consulted during analysis / actions	major exceptions	provide direction for analysis / actions
Check coal edge to LW Toe - width on TOC	dig block	measure with disto, record onto checklist	Shiftly	View checklist, quiz operators	Weekly	GPS, verbal advice to operator, e-mail report to superintendent and engineer. Tie in with bucket service	104	26			weekly	View checklist, discuss with supv and engineer						
Check LW pad RL	dig block	check pegs and design, record actual level onto checklist	Shiftly	view pegs and checklist	Daily (when advancing)	GPS. Provide pegs as required			3 x per week	Read pegs, compare to design, discuss variances with production								
Dragline Ramp Dig																		
Check crest	dig block	pegs	Shiftly	inspect area	2 days	GPS, verbal notification to operator, supervisor and engineer.					weekly	inspect area						
Check toe	dig block	pegs	Shiftly	inspect area	2 days	GPS, verbal notification to operator, supervisor and engineer.			On exception	Assess impacts on design	weekly	inspect area	On exception	discuss as needed and review corrective actions	major exceptions	consulted during analysis / actions	major exceptions	provide direction for analysis / actions
Check ramp width	dig block	measure with disto, record onto checklist	Shiftly	View checklist, quiz operators							weekly	View checklist, discuss with supv and engineer						
Check Levels on ramp vs. design / pegs	dig block	pegs	Shiftly	inspect area	2 days	GPS. Pegs placed as required					weekly	inspect area						
Survey for input into Designs																		
Top of coal within a coal/ptg sequence (eg WWE seam roof)						shot with theodolite												
Highwall toe of basal coal seam "post coal extraction"						10m offset, GPS pickup												
Final pit floor surface pickup						GPS												
Lowwall toe pickup "post coal extraction"					as exposed	shot with theodolite			monthly	discuss upcoming designs with surveyors - identify requirements			2 monthly	Discuss with surveyor / engineer				
Current survey file updated with pickups used in designs (this differs from the current DT as it will still show structure that is beneath						shot with theodolite												
Survey data used to maintain topography model					on going	Continuously update topo model with latest survey pick-ups	104	78	on going	construct topo model using survey data to use in designs			on exception	Discuss with engineer, provide direction on assumptions if necessary				
Survey data not available in time for design					on exception	discuss with planning engineer, make allowances for error			on exception	discuss with planning supt, make allowances for error			on exception	Discuss with engineer, provide direction on assumptions if necessary				
Highwall Markers																		
Chain Highwall as Keys are being dug			<300m highwall exposed without chaining	assess progress of dragline when on keys and plan for dozer to be assigned to keep highwall chaining up to dragline														
Activates to provide access to highwall crests when chaining and Keys completed			Access to within 300m of current DL face	Assign work to dozers to ensure access to high wall crest it established as soon after chaining as possible														
Block markers placed on highwall			2 days	inform surveyor of when to expect access to highwall in order for surveyor to plan for this job to be done	Block markers in place beyond 300m from DL on keys				Each design	Provide string files to surveyor to allow block markers to be placed	weekly	inspect area, assign actions to supervisor when markers not in place	on exception	become involved in working through issues with prod supt if they are ongoing for a long period				
Alternative markers / pegs placed when highwall unaccessable (eg on LW Pad)			as required	when blockmarkers not placed, discuss with surveyor and agree on alternative solution to be used	Maximum period for D/L without blk markers / pegs=7days													
	Geology and Geotech																	
	Geologists		Surveyor		Engineer													
Reconciliation																		
Top of Coal Pick-up (Top Seam)	As Required	Process Data and update model	as required	Scan top of coal with laser	As Required	Liaise with Surveyors to advise of availability of coal seams	182	45.5										
Floor of Pit Pick-up (Bottom Seam)	As Required	Process Data and update model	as required	Scan bottom of coal with laser	As Required	Liaise with Surveyors to advise of availability of coal seams	182	45.5										
Boundaries of Significant Partings	As Required	Process Data and update model	as required	Scan (with Photo) all walls as they become available	As Required	Liaise with Surveyors to advise of availability of parting seams	208	52										
Geological Model																		
Pick ups of Seam floor and roof boundaries as per geological requirements	As Required	Process Data and update model	as required	Scan (with Photo) all walls as they become available	as required	Liaise with Surveyors to advise of availability of parting seams	156	0*	Done as part of previous scans with I-SiTE									
Pick ups of Geological Structures	As Required	Process data and update geotechnical model	as required	Scan (with Photo) all walls as they become available	As Required	Liaise with Surveyors to advise of availability of parting seams	156	0*	Done as part of previous scans with I-SiTE									
							Without I-SiTE	With I-SiTE										
						Total Additional Work Time Surveyors	1612	397										

Appendix D

SURFACE HISTOGRAM DATA

Easting	Northing	Rl	Distance between I-Site survey & GPS survey
318415.700	6390119.000	-58.535	0.497
318413.200	6390135.000	-58.172	1.706
318410.800	6390152.000	-57.844	3.352
318406.700	6390169.000	-57.561	2.338
318388.200	6390257.000	-54.977	1.122
318303.100	6390402.000	-55.533	1.156
318405.800	6390095.000	-20.172	0.936
318401.300	6390113.000	-19.544	2.245
318400.500	6390117.000	-19.352	2.262
318398.300	6390127.000	-18.892	3.027
318394.800	6390144.000	-18.127	2.952
318394.400	6390146.000	-18.041	3.037
318392.400	6390157.000	-17.613	2.732
318388.600	6390175.000	-16.887	3.028
318387.600	6390183.000	-16.503	2.732
318382.800	6390203.000	-15.678	3.259
318380.400	6390216.000	-14.988	3.545
318379.300	6390221.000	-14.722	3.240
318379.000	6390222.000	-14.664	3.247
318377.600	6390230.000	-14.326	2.689
318376.600	6390234.000	-14.124	3.299
318310.300	6390362.000	-12.472	6.774
318305.300	6390367.000	-12.630	1.785
318281.300	6390407.000	-12.635	1.005
318279.200	6390410.000	-12.647	-4.747
318383.500	6390269.000	-43.270	1.530
318389.300	6390241.000	-44.413	1.568
318390.700	6390228.000	-44.690	0.726
318391.400	6390221.000	-45.167	0.514
318394.600	6390209.000	-45.688	1.049
318396.300	6390200.000	-45.923	1.328
318397.000	6390193.000	-45.680	0.881
318400.100	6390182.000	-46.174	1.643
318404.500	6390157.000	-46.784	0.521
318413.900	6390108.000	-47.169	0.989
318385.300	6390182.000	-16.657	3.507
318383.500	6390191.000	-16.313	3.970
318305.100	6390366.000	-12.665	2.095
318308.300	6390362.000	-12.611	6.045
318290.400	6390388.000	-12.706	2.086
318292.200	6390386.000	-12.704	2.098
318291.000	6390387.000	-12.697	2.006
318292.500	6390427.000	-56.644	9.774
318313.600	6390396.000	-55.388	6.113
318314.400	6390395.000	-55.369	6.181
318299.500	6390416.000	-56.179	5.909
318294.100	6390424.000	-56.632	7.847

318307.500	6390405.000	-55.533	5.900
318318.900	6390388.000	-55.259	6.087
318386.700	6390277.000	-54.229	7.157
318389.400	6390269.000	-54.623	5.396
318390.200	6390266.000	-54.708	5.898
318387.800	6390274.000	-54.463	5.198
318395.200	6390241.000	-55.393	4.601
318396.200	6390236.000	-55.509	4.525
318393.200	6390251.000	-55.140	4.752
318391.900	6390258.000	-54.977	4.633
318404.600	6390197.000	-56.574	5.320
318405.600	6390193.000	-56.741	5.270
318403.300	6390203.000	-56.351	5.459
318402.100	6390209.000	-56.200	5.411
318398.100	6390227.000	-55.733	4.745
318400.000	6390218.000	-55.955	4.816
318409.600	6390169.000	-57.561	4.858
318409.900	6390168.000	-57.585	4.891
318406.600	6390187.000	-56.939	5.036
318407.600	6390181.000	-57.156	4.867
318419.500	6390119.000	-58.535	4.301
318419.900	6390117.000	-58.558	4.312
318412.100	6390156.000	-57.775	5.219
318413.800	6390148.000	-57.926	4.970
318416.200	6390135.000	-58.172	4.496
318413.000	6390152.000	-57.844	5.124
318417.300	6390130.000	-58.294	4.430
318421.700	6390107.000	-58.662	5.324
318287.700	6390396.000	-12.625	1.790
318281.800	6390406.000	-12.633	0.929
318287.900	6390421.000	-45.811	6.178
318291.100	6390423.000	-56.632	6.234
318309.100	6390363.000	-12.510	5.335
318301.700	6390374.000	-12.626	1.063
318300.600	6390376.000	-12.599	0.961
318299.100	6390379.000	-12.568	1.432
318292.700	6390390.000	-12.519	1.366
318291.800	6390391.000	-12.538	1.524
318294.400	6390388.000	-12.501	1.405
318375.700	6390239.000	-13.951	2.747
318374.700	6390247.000	-13.683	1.947
318373.500	6390253.000	-13.435	1.723
318374.000	6390251.000	-13.574	1.741
318382.900	6390203.000	-15.691	3.295
318385.500	6390191.000	-16.198	3.225
318390.600	6390164.000	-17.384	3.227
318388.900	6390173.000	-16.960	3.215
318388.100	6390180.000	-16.611	2.578
318386.300	6390253.000	-44.070	1.332
318380.900	6390213.000	-15.125	3.012
318381.300	6390274.000	-43.313	6.318

318385.500	6390273.000	-54.463	3.824
318385.000	6390261.000	-43.748	1.052
318402.900	6390105.000	-19.864	2.186
318399.300	6390123.000	-19.099	3.444
318397.800	6390129.000	-18.798	3.067
318407.400	6390147.000	-47.047	1.096
318396.600	6390136.000	-18.501	2.691
318406.800	6390087.000	-20.536	5.627
318406.700	6390088.000	-20.515	5.131
318402.300	6390166.000	-46.680	0.812
318393.300	6390151.000	-17.854	3.341
318390.800	6390163.000	-17.429	3.372
318396.000	6390138.000	-18.382	2.753
318401.800	6390171.000	-46.171	1.155
318402.900	6390186.000	-56.939	1.333
318399.700	6390203.000	-56.351	2.525
318396.200	6390218.000	-55.955	-1.012

Appendix E

NPV SCENARIO 1 & SCENARIO 2

Scenario 1

Purchase I-site Laser		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
		1	2	3	4	5	6	7	8	9	10
ASSUMPTIONS/RATES											
Life of Asset	5.0 yrs										
Depreciation		20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Inflation Factor		0.0%	2.7%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%
Inflation Multiplier		100.0%	102.7%	105.7%	108.7%	111.9%	115.1%	118.5%	121.9%	125.5%	129.1%
Tax Rates:		30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
CAPITAL EXPENDITURE											
Purchase I-site Laser	Real A$,000	$ (215,000)									
TOTAL CAPITAL EXPENDITURE	Nominal $,000	$ (215,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CASH OUTFLOWS											
Maintenance & warranty costs	Real A$,000		$ (17,500)	$ (17,500)	$ (17,500)	$ (17,500)		$ -	$ -	$ -	$ -
TOTAL CASH OUTFLOWS	Nominal $,000	$ -	$ (17,973)	$ (18,494)	$ (19,030)	$ (19,582)	$ -	$ -	$ -	$ -	$ -
CASH INFLOWS											
Third party monthend survey savings	Real A$,000	$ 48,000	$ 48,000	$ 48,000	$ 48,000	$ 48,000		$ -	$ -	$ -	$ -
Additional surveyor not required	Real A$,000	$ 119,000	$ 119,000	$ 119,000	$ 119,000	$ 119,000		$ -	$ -	$ -	$ -
Additional cast assist	Real A$,000	$ 60,900	$ 60,900	$ 60,900	$ 60,900	$ 60,900		$ -	$ -	$ -	$ -
	Real A$,001										
	Real A$,000		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL CASH INFLOWS	Nominal $,000	$ 227,900	$ 234,053	$ 240,841	$ 247,825	$ 255,012	$ -	$ -	$ -	$ -	$ -
TAX EFFECTS											
Depreciation		$ 43,000	$ 43,000	$ 43,000	$ 43,000	$ 43,000	$ -	$ -	$ -	$ -	$ -
Written Down Value		$ 172,000	$ 129,000	$ 86,000	$ 43,000	$ -	$ -	$ -	$ -	$ -	$ -
Tax Effects of Capital Expenditure		$ 12,900	$ 12,900	$ 12,900	$ 12,900	$ 12,900	$ -	$ -	$ -	$ -	$ -
Tax Effects of Cash Outflows		$ -	$ 5,392	$ 5,548	$ 5,709	$ 5,875	$ -	$ -	$ -	$ -	$ -
Tax Effects of Cash Inflows		$ (68,370)	$ (70,216)	$ (72,252)	$ (74,348)	$ (76,504)	$ -	$ -	$ -	$ -	$ -
NET CASH FLOW	Nominal $,000	$ (42,570)	$ 164,157	$ 168,543	$ 173,057	$ 177,701	$ -	$ -	$ -	$ -	$ -
NET CASH FLOW	Real A$,000	$ (42,570)	$ 159,841	$ 159,487	$ 159,143	$ 158,809	$ -	$ -	$ -	$ -	$ -
Discount Factor	8.0%	0.96	0.89	0.82	0.76	0.71	0.65	0.61	0.56	0.52	0.48
Discounted Cash Flow @ 8.0%	Real A$,000	$ (40,933)	$ 142,308	$ 131,475	$ 121,474	$ 112,239	$ -	$ -	$ -	$ -	$ -
Cumulative DCF		$ (40,933)	$ 101,376	$ 232,851	$ 354,325	$ 466,564	$ 466,564	$ 466,564	$ 466,564	$ 466,564	$ 466,564
NPV, 8%	**Real A$,000**	**$ 466,564**									
IRR		**375%**									
Payback		**1.0 yrs**									
Pre Tax Operating Profit		$ 184,900	$ 173,081	$ 179,347	$ 185,795	$ 192,430	$ -	$ -	$ -	$ -	$ -
After Tax Cash Flow		$ (42,570)	$ 164,157	$ 168,543	$ 173,057	$ 177,701	$ -	$ -	$ -	$ -	$ -

Scenario 2

Purchase I-site Laser		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
		1	2	3	4	5	6	7	8	9	10
ASSUMPTIONS/RATES											
Life of Asset	5.0 yrs										
Depreciation		20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Inflation Factor		0.0%	2.7%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%
Inflation Multiplier		100.0%	102.7%	105.7%	108.7%	111.9%	115.1%	118.5%	121.9%	125.5%	129.1%
Tax Rates:		30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
CAPITAL EXPENDITURE											
Purchase I-site Laser	Real A$,000	$ (215,000)									
TOTAL CAPITAL EXPENDITURE	Nominal $,000	$ (215,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CASH OUTFLOWS											
Maintenance & warranty costs	Real A$,000		$ (17,500)	$ (17,500)	$ (17,500)	$ (17,500)		$ -	$ -	$ -	$ -
TOTAL CASH OUTFLOWS	Nominal $,000	$ -	$ (17,973)	$ (18,494)	$ (19,030)	$ (19,582)	$ -	$ -	$ -	$ -	$ -
CASH INFLOWS											
Third party monthend survey savings	Real A$,000	$ 48,000	$ 48,000	$ 48,000	$ 48,000	$ 48,000		$ -	$ -	$ -	$ -
	Real A$,000		$ -	$ -	$ -	$ -		$ -	$ -	$ -	$ -
Additional cast assist	Real A$,000	$ 60,900	$ 60,900	$ 60,900	$ 60,900	$ 60,900		$ -	$ -	$ -	$ -
	Real A$,001										
	Real A$,000		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL CASH INFLOWS	Nominal $,000	$ 108,900	$ 111,840	$ 115,084	$ 118,421	$ 121,855	$ -	$ -	$ -	$ -	$ -
TAX EFFECTS											
Depreciation		$ 43,000	$ 43,000	$ 43,000	$ 43,000	$ 43,000	$ -	$ -	$ -	$ -	$ -
Written Down Value		$ 172,000	$ 129,000	$ 86,000	$ 43,000	$ -	$ -	$ -	$ -	$ -	$ -
Tax Effects of Capital Expenditure		$ 12,900	$ 12,900	$ 12,900	$ 12,900	$ 12,900	$ -	$ -	$ -	$ -	$ -
Tax Effects of Cash Outflows		$ -	$ 5,392	$ 5,548	$ 5,709	$ 5,875	$ -	$ -	$ -	$ -	$ -
Tax Effects of Cash Inflows		$ (32,670)	$ (33,552)	$ (34,525)	$ (35,526)	$ (36,557)	$ -	$ -	$ -	$ -	$ -
NET CASH FLOW	Nominal $,000	$ (125,870)	$ 78,607	$ 80,513	$ 82,474	$ 84,491	$ -	$ -	$ -	$ -	$ -
NET CASH FLOW	Real A$,000	$ (125,870)	$ 76,541	$ 76,187	$ 75,843	$ 75,509	$ -	$ -	$ -	$ -	$ -
Discount Factor	8.0%	0.96	0.89	0.82	0.76	0.71	0.65	0.61	0.56	0.52	0.48
Discounted Cash Flow @ 8.0%	Real A$,000	$ (121,029)	$ 68,145	$ 62,806	$ 57,891	$ 53,366	$ -	$ -	$ -	$ -	$ -
Cumulative DCF		$ (121,029)	$ (52,883)	$ 9,922	$ 67,813	$ 121,179	$ 121,179	$ 121,179	$ 121,179	$ 121,179	$ 121,179
NPV, 8%	**Real A$,000**	**$ 121,179**									
IRR		**48%**									
Payback		**2.1 yrs**									
Pre Tax Operating Profit		$ 65,900	$ 50,868	$ 53,590	$ 56,391	$ 59,273	$ -	$ -	$ -	$ -	$ -
After Tax Cash Flow		$ (125,870)	$ 78,607	$ 80,513	$ 82,474	$ 84,491	$ -	$ -	$ -	$ -	$ -

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