University of Southern Queensland

Faculty of Health, Engineering and Sciences

Accuracy of a Machine Guided Grader

A Dissertation submitted by

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Abstract

Machine Guidance is used regularly in construction of roads to aid performance of heavy machinery such as Graders. Machine Guidance technology has the ability to tell the grader operator what height he is cutting to compared to the road design and even control the height of the Graders Blade if required.

This research project analyses the accuracy of a Machine Guided Grader that is used in the formation of roads we use every day. The author demonstrates the accuracy by comparing heights recorded from the grader to heights surveyed in the field. For ease of use and convenience a Trimble Guided Grader is studied with the most up to date grader control system. The Trimble Guided Grader is supported by a Trimble SPS930 total station achieving 1” of error in the Vertical and Horizontal circles. Teaming up of both these systems gives the best opportunity for accurate results whilst eliminating the likelihood of bias creeping in.

Modern Trimble Guided Grader technology has the ability to record the finished surface constructed through a simple push of a button. This surface can then be used in quality and production reports replacing the need for a surveyor to manually survey the area every time. Field Tests were carried out using this surface to compare against what is surveyed off the range pole producing a set of differences between the two approaches. Two field tests were carried out with results showing an average difference of 0.3mm in one test and 3.9mm in the second giving the author confidence to conclude that the accuracy generated from a machine guided grader blade was demonstrated to within 4mm of the actual surveyed surface.

The 4mm accuracy demonstrated that opportunities do exist in using the recorded surface as a formal document at times replacing the conformance report that is used for quality assurance purposes. The vision of this occurring would only be achieved through education and research that demonstrated the accuracy to clients like the Department of Transport and Main Roads.

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ENG4111 / 4112 Research Project

Limitations of Use

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.

Mitchell Bell

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Signature

2nd October 2013

Date

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I would also like to thank my place of work and sponsor of the research, Seymour Whyte Constructions Ltd. All the staff have been very accommodating throughout the project with an abundance of help coming from Tom Williams, Anthony Mercer and John Hartley. Without your guidance and support a lot of things simply would not have happened. So thanks.

I would finally like to thank my wife, Sarah for all of her patients help and support throughout the busy year.

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List of Acronyms

1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
ANOVA	Analysis of Variance
ATS	Advanced Tracking Sensor
CAD	Civil Aided Design
COGO	Coordinate Geometry Calculations
CSV	Comma Separated Values
CTB	Cement Treated Base
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DTMR	Department of Transport and Main Roads
FSL	Finished Surface Level
GCS900	Grader Control System 900
GPS	Global Positioning System
Km/h	Kilometres Per Hour
LED	Light Emitting Diode
M	Metre
MHz	Megahertz
mm	Millimetre
m/s	Metres Per Second
OS	Offset
PPM	Parts Per Million
RL	Reduced Level
RTS	Robotic Total Station
SCS900	Site Controller Software 900
SPS930	Site Positioning System 930
SVO	Site Vision Office
SWL	Seymour Whyte Constructions Limited
TBC	Trimble Business Centre
TIN	Triangulated Irregular Network

TSC3	Trimble Site Controller 3
UTS	Universal Total Station

1. Introduction

Machine Guidance or Machine Control, what is the difference and what does it actually do…. Financial investment within this area of technology is substantial and benefits to the construction industry have been significant. But do investors of this technology fully understand what machine guidance or machine control is capable of producing? Is the investor applying their machine guided grader to its maximum capability?

A large part of a surveyor's day in the construction industry is to provide as-constructed reports for quality assurance purposes. The as-constructed drawings and reports are requested by the client and used as a formal document to ensure the job is done correctly prior to payment being made. These drawings are then archived for future reference when required.

Now what a lot of clients and contractors in the construction industry don't realise is that machine guidance software now has the ability to track and record the area the machine has covered over the course of the day. Roller operators can choose when to start counting the number of passes he makes in the roller to ensure optimum compaction. Or the Grader operator can choose when to record the surface he/ she is producing to show production and quality achieved.

The author believes that opportunities exist in using the Grader to record the produced surface providing a more comprehensive report and freeing up time for the surveyor.

The purpose of the research is to provide greater insight into the true accuracy achieved by running a Machine Guided Grader on a construction job. By using some of the latest technology, field research aims to analyse the Graders ability to record the Finished Surface Level (FSL). The Field Tests are designed to ensure the highest accuracy possible from the equipment available while still achieving the projects aim and objectives.

This report aims to assist the reader in achieving a better understanding of Machine Guided Grader technology whilst taking a closer look at what accuracy is generated from a Machine Guided Grader blade. A key aspect of the research is analysing Graders that use the Trimble

3D Grade Control System (GCS900) using a Universal Total Station (UTS). The Trimble manufacturer claims this system can achieve blade control to 5 millimetres on the Trimble SPS930 or SPS730 UTS system (Trimble, 2013g). I aim to test this in my studies while also testing the capability, reliability and accuracy of producing a conformance report from the blade of the grader.

1.1 Project Aim

To demonstrate the accuracy generated by a Machine Guided Grader blade.

1.2 Objectives

1. Research machine guided graders used within Australia's construction industry.
2. Evaluate current usage of machine guided graders with particular emphasis on survey accuracy.
3. Conduct a study on the accuracy of a Trimble machine guided grader by comparing heights recorded from the grader to heights surveyed in the field.

2. Background Information

Over the years technology on construction sites has advanced. Surveyors previously would place pegs/stakes on grade and chainage to indicate cut or fills required in bulk earthworks. The stake would read 'CH1510 MC40, OS 1m ES, F500 FSL'. This would translate to Chainage 1510 on control line MC40, 1 metre offset to edge of shoulder, fill 500mm to finished surface level. The grade checker reads the peg and passes this information onto the grader, bulldozer or excavator. Tools the grade checker used were basic and did the job well, these included stringlines, tape measures, hand signals, and a radio. The manual process was prone to errors, time consuming and required more on hand construction staff. This method carried an increased risk as it required staff to work closely with heavy machinery.

2.1 Quality Assurance

Part of the Quality Assurance process clients like the Department of Transport and Main Roads (DTMR) are asking for is a Conformance Report. A Conformance Report is a certificate of quality assurance that says the product specified is at a certain level of conformance. It either passes the required tolerance or it doesn't. Conformance is defined in Dictionary.com as "compliance in actions, behaviour, etc., with certain accepted standards or norms". (Dictionary.com, 2013).

Once the product conforms to the required standard it can be signed off and the next stage can commence. Now modern day machines have the ability to speed up this process producing a conformance report showing the final height of the road layer. With calibration, knowledge and trust of the product, a Conformance Report produced from the graders blade can be quite powerful. It eliminates the need for a surveyor to physically survey the layer of material in question, and in doing so streamlines the whole process. This can be taken a step further if desired by the contractor as Trimble 3D Grade Control Systems have the ability to be connected to a VisionLink Fleet and Asset Management system. The VisionLink Fleet and Asset Management system features user-friendly management tools combined with GPS-based positioning and cellular technology to provide near real-time equipment performance information (Trimble, 2013i). Information that can be used in the conformance report and uploaded onto the VisionLink website for use by all people that have access. This information can influence future management decisions and profitability.

2.2 Early History of Machine Guidance

Since the earlier grade checker days Machine Guidance systems have developed from a basic 1 dimensional (1D) system to a 2 dimensional system (2D) then onto a fully automated 3 dimensional (3D) system. The 1D rotating laser system would indicate to the operator whether the blade should be raised or lowered based on the sensor attached to the blade of the grader. The sensor picks up the rotating laser and LED lights indicate whether the blade should be raised or lowered (Surveys, 2013). The 2D machine guidance system follows on from the 1D but with added benefits allowing the operator to view the blade on a screen inside the cab, the grade of the blade is given to the operator, and better accuracy is achieved. Following these the 3D machine guidance system was developed adding the horizontal position of the grader into the picture. Positional information is supplied into the cab from either a Universal Total Station (UTS) or a Global Positioning System (GPS). This information can be accurate to 5mm on a UTS setup and 20mm on a GPS setup and is used to compare against design position of the surface under construction to compute a cut or fill measurement. The data can be shown digitally for the operator or be used to control the hydraulics of the machine (Surveys, 2013). With the latest technology, the grader operator just needs to focus on driving the machine while the computer software calculates and adjusts the blade height all by itself.

2.3 Design Surfaces

To generate a cut or fill level required in the cab of the machine a design surface must be compared against an as-constructed position. The design position calculates a height off the design surface on the model. The surface is usually called a Digital Terrain Model (DTM) or Digital Elevation Model (DEM) and is based on a triangulated irregular network (TIN) or a raster grid. “The TIN represents a surface of continuous non overlapping triangles, within each triangle the surface is represented by a plane” (Tchoukanski, 2012). The TIN is common to machine guidance and will be used to generate the design surface for the grader.

2.4 Machine Guidance Defined

There is a lot of new terminology in the field of surveying as it is evolving everyday so a number of new terms will be discussed. The machineguidance.com website defines "*Machine Automation* as a form of machine control technology that not only displays the machines position over a design model but also directly controls the machines ground engaging tools. By controlling the machine hydraulics the system is able to move the blade towards the correct grade allowing the operator to concentrate on driving the machine". "*Machine Control* is the generic term used to define the integration of survey positioning devices with construction plant". *Machine Guidance* a form of machine control technology that is indicate-only. The system is able to guide the operator to the correct position and grade by showing the current machine position against the desired design" (Guidance, 2013).

2.5 Range of Products

In 2013 a lot of machinery used on large roading jobs have machine control. These range in type of machine control and accuracy gained from using the product. A study conducted in 2010 named The Kellogg Report cites a number of different systems that are available on the market for use in graders. Machine Control systems can be used in graders, dozers, excavators, scrapers, paving machines, rollers and draglines through many different manufacturers. Manufacturers listed in the Kellogg report include Trimble, Topcon, Caterpillar, Leica, and Prolec (LLC, 2010-11). This report aims to test a Trimble Guided Grader.

3. Literature Review

This Literature Review has not been able to locate information that specifically addresses the accuracy of a Machine Guided Grader Blade. Or find information that specifically researches a conformance report produced off the graders blade. Perhaps due to Trimble not designing a construction compatible product solely for producing a conformance report from the blade of the grader.

With this in mind I have been able to identify some key conclusions made from previous studies on accuracy of a Trimble UTS.

- In 2010 Kiongoli looked at operational accuracy of several instruments the latency and the range of products. Kiongoli concluded that “the latency caused by distance time measurements in Advanced Tracking Sensors (ATS) is the most critical factor associated with an ATS performance in terms of accuracy and reliability” (Kiongoli, 2010).
- In 2005 Garget investigated the Testing of Robotic Total Stations for Dynamic Tracking and concluded that latency caused by distance time measurement is the most critical factor associated with a Robotic Total Stations (RTS) performance in terms of its accuracy and reliability” (Garget, 2005). The result for the Trimble instrument was of inferior quality compared to the Leica. Garget compared two instruments of a different specification; the Leica had a specification of 5mm +/- 2ppm, the Trimble 10mm +/-2ppm. Garget also concluded that “the Trimble similar to the Leica performed best over a range of approximately 50m however the ideal speed was lower at 0.17m/s” (Garget, 2005).
- In 2004 Chua also did a similar report titled Testing of Robotic Total Stations for Dynamic Tracking. He also concluded that “the reliability of the Robotic Total Station (RTS) is greatly related to the speeds of the prism and measurement distances (Chua, 2004).

In summary there are some distinct similarities between the three report conclusions stated above. All make reference to three main factors:

1. Speed of the moving target
2. Measurement distance to the target
3. Latency of the system

After discovering accuracy loss through the speed of a moving target I investigated my own situation. The Trimble SPS930 UTS has a stated vertical accuracy of 1" but has a +/- 2mm+14ppm (parts per million) accuracy to a moving target at 1m/s (metre per second) (Trimble, 2013d). My objective is to conduct a study on the accuracy of a Trimble Machine Guided Grader by comparing heights recorded from the grader to heights surveyed in the field I need to ensure speed is kept to a minimum and is consistent throughout all of the research.

In order to gauge a good measure on what affect speed is having on the accuracy of the system I shall record the surface twice at two different speeds. One surface at 0.5m/sec and the other at 1m/sec.

The measurement distance to the target will be kept as consistent as possible throughout the field testing by ensuring the UTS is positioned in the middle of the study area. By doing this I gain consistent horizontal distances to either end of the sample area. For a Study area that is 200 metres long the UTS will sit in a central position and off to one side so it measures a similar distance to both ends of the study area. This will help eliminate any potential vertical errors by recording measurements that are 200 metres away to one end and only 10 metres to the other end. Keeping the UTS in a central position will eliminate the potential to compromise the results through increased vertical error at one end of the sample area.

Latency has been studied in many different situations previously. All three reports referred to Latency at some stage throughout their research. It is a term used to describe "a measure of time delay experienced in a system" (University, 2013) and has the ability to cause changes in the results if not understood correctly. In order to reduce the effects of Latency in the system speed will be kept consistent at two nominated speeds and measurement distance will be kept as even as possible between samples.

4. Implications and Consequential Effects

4.1 Success or Failure

My project has the ability to be a success or a failure to readers of it. The sponsor company Seymour Whyte Constructions Ltd (SWL) would desire the project to be a success with regard to accuracy of the Trimble Guided Grader. As SWL is investing considerable time, money and energy into the new technology. For example the Landsborough Highway job just out of Longreach has ten graders running on it at the moment all with machine control, and about five graders are running a Universal Total Station (UTS) system gaining less than 5mm accuracy in height off the blade. A failure in accuracy would question the products used by SWL to build the roads we are involved in.

A success in proving that a grader can produce an accurate reliable conformance report off the blade would be beneficial for SWL. This would mean the surveyor would only need to do spot checks at the end of the graders day and possibly not every day. A competent operator should have the ability to do his own checks at the end of the shift and during the shift by checking against known benchmarks. This gives the surveyor more time to concentrate on other tasks increasing efficiency and decreasing costs ideally being beneficial to the bottom line.

4.2 Limitations of Study

One limiting factor in this study is that I cannot physically carry out numerous studies in many different areas on many different machines. Ideally I shall carry out three separate studies on the same grader with the same Total Station. This part of my research needs to be kept as simple as possible to minimise the potential for bias in the results obtained. As long as the potential for bias is recognised within the research project to all readers of this report then all precautions can be taken to minimise it. Ideally bias will not be one of the consequential outcomes.

5. Methodology

In order to achieve the project objectives outlined earlier methodology needs to be applied to ensure steps are taken in the correct order with the same goal in mind. The steps are outlined throughout this chapter.

Field Research

5.1 Calibration

Good research in the field is essential in achieving the aim of the project. All equipment needs to be calibrated correctly and in good working order. This will involve calibrating the grader, the total station, and the pole.

The Trimble Guided Grader has four different sensors and an electric mast that require calibration. The sensors must be calibrated when a new sensor is added, or installed sensors are moved to new locations (Trimble, 2010a). Prior to carrying out any research calibration of the "Mainfall, Blade Slope and Rotation sensors" is required. A large hard flat surface is essential with enough room to turn the machine around. Firstly the grader is positioned square and straight with a vertical blade and mast. Four tyres and the cutting blade are marked as shown in position 1.

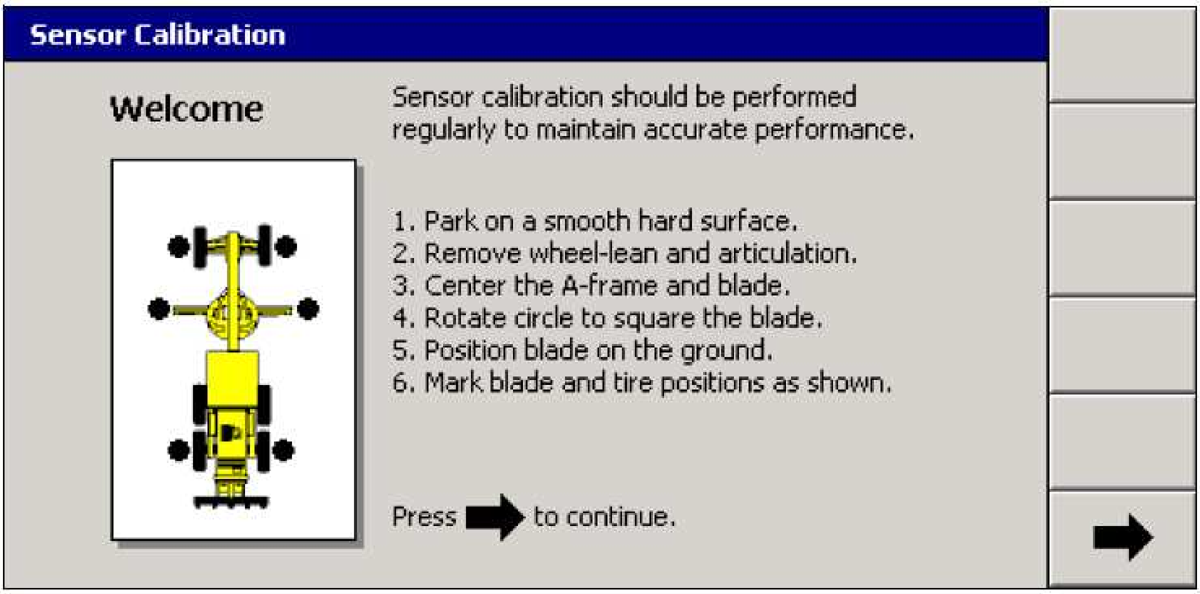

Figure 5-1 Sensor Calibration Position 1

Once in position 1 the continue key is pushed to calibrate the rotation sensor, readings are taken for the Mainfall and Blade Slope sensor calibration. Next raise the blade and turn the machine 180° without articulating the machine, leaning the wheels or changing the circle position while executing the turn (Trimble, 2010a).

The grader blade is positioned back over the marks as in position 2.

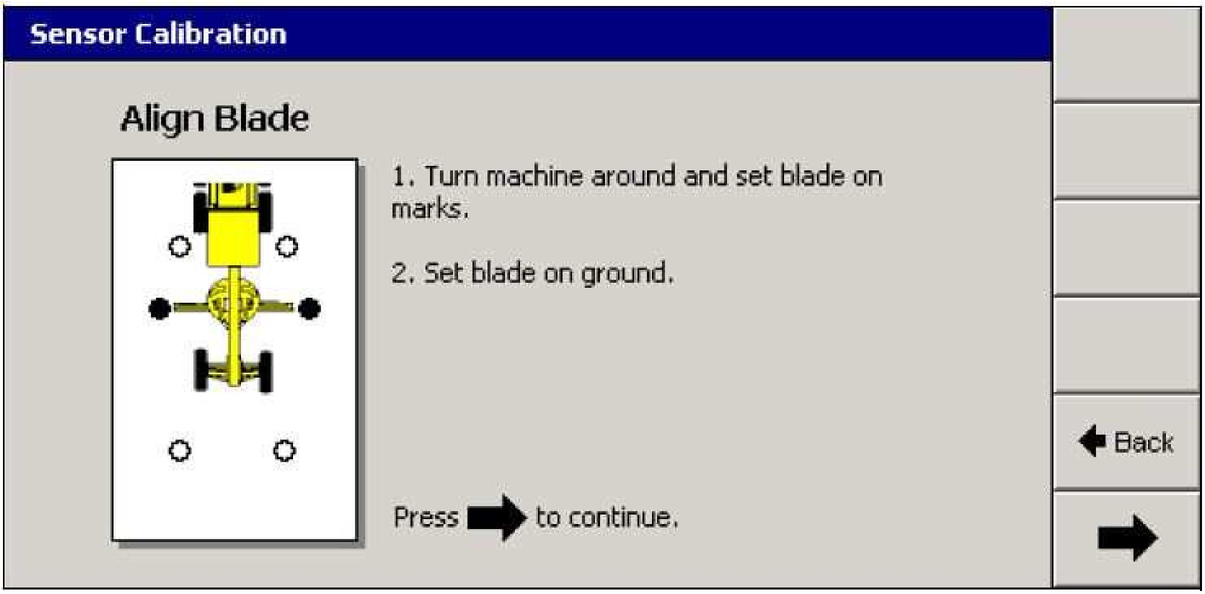

Figure 5-2 Sensor Calibration Position 2

After pressing continue readings are taken calibrating the blade slope sensor. The blade is then lifted allowing the grader to move forward so that the tyre marks move onto position 3.

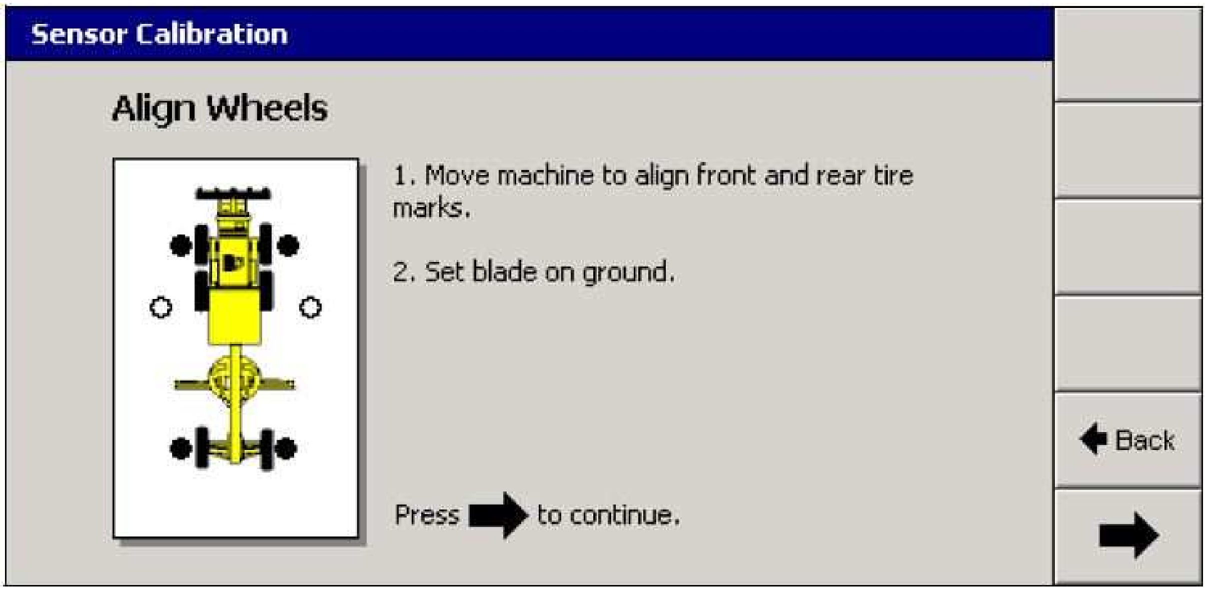

Figure 5-3 Sensor Calibration Position 3

After pressing continue in position 3 the Mainfall sensor is calibrated completing the process.

The fourth sensor that is not checked above is the Blade Pitch Sensor. It can be calibrated through placing a spirit level on the mast ensuring verticality and pressing calibrate.

The Total Station needs to be calibrated for consistency and accuracy of field research, as well as the adjustable pole.

5.2 Site Knowledge

In days building up to our field research day the grader and the total station would have been used together on laying Cement Treated Base (CTB) before, so the chances of a breakdown are minimised. The Surveyor and Operator have had time together building up some trust between them and their technology. Both are familiar with the work area, how it should be laid out and what works well for them. On previous runs the Surveyor has checked the work of the grader and found minimal high and low spots on the finished surface. All staff have the confidence that the combinations of equipment will work consistently on the day.

On Field Research day at least 300 tonnes of CTB will be placed in the work area at 150mm thick. The Engineers and Supervisors will look after delivery and access for the trucks while the Surveyor will look after the spatial side of the operation. This will involve finding a suitable location for the UTS system, the area needs to be stable and free from obstructions and vibration from heavy machinery. The UTS will be coordinated onto the jobs coordinate system and checked against known control stations.

5.3 Benching the Grader

Prior to disconnecting from the UTS the surveyor will place at least two benchmarks of known elevation in an easily accessible spot for the grader. Then the surveyor will apply a search window and switch the UTS onto machine control mode taking note of the channel and network being used.

The grader operator uses the Grade Control System (GCS900) software and a 2.4MHz radio to connect to the UTS through the channel and network applied earlier. Once lock is achieved the grader operator needs to engage a low gear and slowly move forward until the mast and blade are positioned directly over the benchmark. The elevation is then transferred accurately onto the blade with a measuring tape and spirit level. The known elevation of the blade is entered into the Grade Control System 900 (GCS900) software to achieve accurate levels.

Next the grader operator moves forward checking onto the second benchmark, again the known elevation is transferred onto the blade with a measuring tape and spirit level. The elevation can now be checked against what is shown on the screen to confirm the accuracy.

5.4 Road Design

The GCS900 software runs off two different design files a svl file and a svd file. Both are created in Trimble Business Centre (TBC) a Civil Aided Design (CAD) software package used for road design. The files are loaded up onto the GCS900 and used to guide and/or automate the grader.

5.5 Spreading of Road Base

Using the GCS900 the operator selects the correct design and vertical offset before choosing either manual or automatic mode. The operator may choose to use manual mode to spread the CTB around the work area to achieve a more uniform state. Once this has occurred automatic mode should be selected to ensure the most accurate result. The GCS900 adjusts the blade according to the svd file that has been loaded up in the design. Once final height is achieved the flat drum roller will need to make a final pass over the road base gaining optimum compaction.

5.6 Reporting of Finished Surface Level (FSL)

Trimble Guided Graders that use the GCS900 software now have the ability to record the height of the blade in the field and generate a Triangulated Irregular Network (TIN). It is through this generated surface I look to analyse and dissect identifying the real accuracy of the TIN. So once the roller has finished with the CTB the grader needs to make a number of passes over the finished product in record mode creating the TIN. The TIN or surface will then be used for a direct comparison against the manually surveyed points. Once the grader has disconnected I shall reconnect with my TSC3 controller and 2.5m adjustable pole. The same pole was used to apply an elevation to the benchmark for the grader. Ideally a minimum of 30 points will be sampled evenly spaced on a grid of at least 3 points across the surface occurring every 10 metres for 100 metres. I shall find the horizontal position for the surveyed point first then recording the shot in standard measurement mode achieving the vertical accuracy stated of 1” (Trimble, 2013b).

The recorded results will give me an opportunity to apply some mathematics proving the accuracy of the Machine Guided Grader Blade.

5.7 Proving the Accuracy

To prove the accuracy of the TIN generated from the grader blade mathematics needs to be applied giving the results a degree of confidence in a professionally structured approach. I plan to calculate the sample mean (ẋ) and the sample standard deviation (s) and place a level of confidence on the results.

In order to analyse the results further an Analysis of Variance (ANOVA) test or Fishers F-test will be used which makes a statistical comparison between the variances of two data sets.
The F test compares a variance against two hypotheses

H_O: There is no difference between the two variances

$H_{A:}$ larger variance s^2_1 is significantly different than the smaller variance $s^2_{1.}$ (Leicester, 2000)

If the calculated value is greater than the critical value we need to reject the H_O at the chosen level of confidence. The F-test will gain a more accurate view of the relationship between the Field Tests we have sampled.

In the field I plan to do three tests assessing the accuracy of the grader report. By doing this I increase my sample size from say 30 sample points to around 90 giving increased opportunity to detect differences that may occur due to circumstances out of my control. Ideally the three tests conducted will have the same operator, same grader and same UTS system with slight differences in design giving us more realistic results of what accuracy the report would achieve. Some possible sample scenarios are below:

- Sample 1 - Has minimal vertical change with a 3% cross fall on a straight piece of road.
- Sample 2 - Has 1 -2% change in vertical alignment on a straight piece of road with a 3% cross fall.
- Sample 3 - Has minimal vertical change running through it, a crown down the middle and -3% and 3% cross falls either side.

- Sample 4 - Has 3% cross fall and is heading around a corner with 1-2% change in vertical alignment.

Once three field testing samples have been conducted tests will be undertaken to assess differences in the data. The F-Test can be used here to test whether two observed samples have the same variance. Also whether results from one particular design of road are better than another design of road.

5.8 What is Accurate

Once I have proved the Field Testing results have an accuracy of say +/-5mm where does one draw the line as to when this is an acceptable measure of accuracy. For example is +/-10mm going to be close enough or do we need to have results which are +/-3mm. Ultimately a "What is Accurate" tolerance needs to be determined by the client. The surveyor can just apply his or her knowledge to the subject and place a measure of accuracy on the report generated from the graders blade. Once this is placed it is up to the client as to whether they want to accept a new style of producing the Conformance Report.

Clients and Readers of this research project need to be mindful that I am testing the accuracy of a Machine Guided Grader Blade with a UTS system that has errors of its own. There will be two types of errors happening. The SPS930 has a stated vertical accuracy of 1" but has a +/-2mm+14ppm (parts per million) accuracy to a moving target at 1m/s (metre per second) (Trimble, 2013b). When the grader operator is doing his final pass and recording the surface it is important that the speed is kept to an absolute minimum. Less than 1m/s or 3.6km per hour to ensure accuracy of the recorded surface.

For simplicity I shall be aware of the 1" vertical error of the SPS930 but will not include it in my final results

6. Safety Issues

The general public image of construction activities is that it is a high risk noisy environment. This does not have to be the case. Safety in Construction has come a long way over the years with less injuries occurring. Ideally I will be gaining access to three different areas which could range in location, topography, and climate. Sites are still being confirmed but have the potential to be located on the Toowoomba Range, Warrego Highway (Jondaryan to Dalby) Bruce Highway (Back Creek Range – Gin Gin) or Landsborough Highway (Longreach) which are all major highways carrying high volumes of traffic at speeds up to 100km/h. The safety risks associated with conducting grader accuracy testing include:

1. Driving to and from the Job Site.
2. Driving on the Job Site.
3. Unloading of gear.
4. Working in close proximity to heavy machinery.

6.1 Driving to and from the job site

Driving to and from the job site involves driving on the open road at speeds up to 100km/h with nothing but a white painted line between the car and the ditch or between the car and oncoming traffic. We do this every day and should never take driving to and from the job site (or work) for granted. Seat belts should always be worn, speed limits obeyed and drivers should always drive to the conditions taking regular breaks.

6.2 Driving on the job site

In conjunction with driving to and from the job there will be driving on the job site for the task at hand. All Construction Sites are speed limited to either 40km/hr or 20km/hr which gets reduced to 10km/hr around workers. Many other hazards on the site include moving machinery, workers, open excavations, tools, and other light vehicles. Preventative measures that are used to minimise the risk on the job site include reducing the speed limit, designated haul roads, high visible (high vis) clothing, flashing lights, radio communication, traffic control, gatekeeper, dogman (spotter), seat belts, and positive communication.

6.3 Unloading of gear

Once in the work area all the survey gear needs to be unloaded and setup in a safe position. Correct lifting techniques are to be used by bending at the knees for heavy lifting. The UTS will be setup in a safe location, off haul roads and ideally to the edge of the graders work area. The area would be slightly elevated and have a clear line of sight to where the grader is working. Before the work starts methodology of how the day's activities will run is decided upon and communicated to all staff. This includes access for the large truck and dog trailers that will arrive with road base. The access generally goes in a circuit, so to gain good visual contact between the grader and the total station a good system is needed. Grader operators generally prefer the UTS to be placed behind them. This helps when truck and dog trailers unload the Cement Treated Base (CTB) the truck is not between the grader and the UTS. Instant visual contact allows the grader operator to be more efficient by starting to spread the CTB straight away and also leave the grader in automatic blade control mode.

6.4 Working in close proximity to heavy machinery

In order to carry out my studies I will be working in close proximity to the grader. Prior to use the grader needs to be benchmarked against a known reduced level (RL). This involves placing an RL in an accessible location to the grader. Moving the grader so the blade is positioned directly over the RL and measuring the height from the blade to the RL. To achieve this good communication between the Surveyor and Operator is a must. The Surveyor will only approach the grader blade once the handbrake has been placed on and positive communication between the Surveyor and Grader Operator has occurred.

The grader is a big piece of machinery with many blind spots. Blind spots are an area where clear vision for the operator does not occur, and the operator is running blind in that particular zone. A good idea for the surveyor is to sit in the cab and take a look in the mirrors so he can actually see where the major blind spots are. The diagram below is from the United States Mine Rescue Association and shows blind spots highlighted in grey.

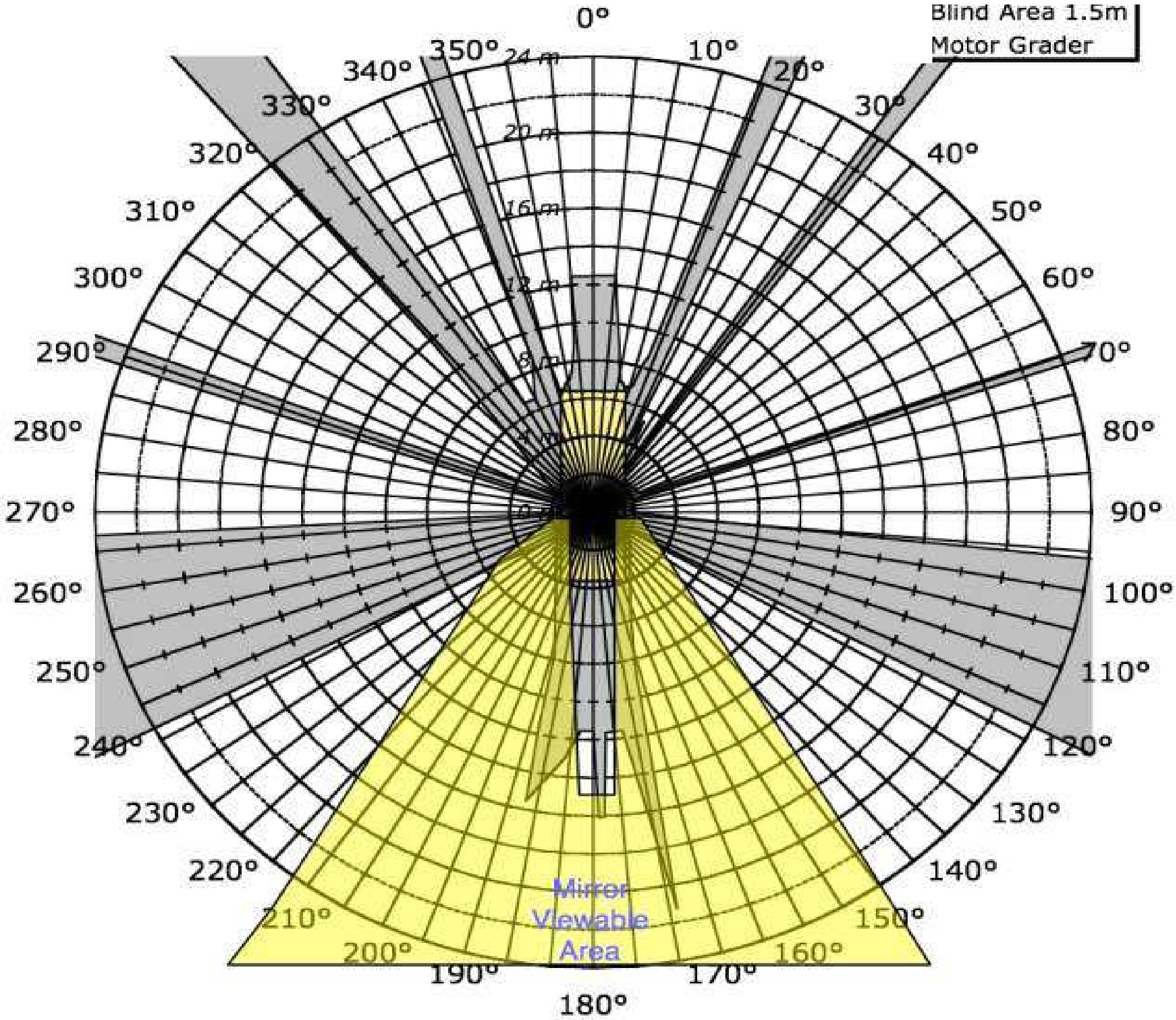

Figure 6-1 Blind Spots Study

Viewed 16/5/2013 (Association)

7. Resource Requirements

A number of different resources are required all being equally as important as the other. To obtain all of the resources required and coordinate them on the same day takes good communication and cooperation from my work colleagues at SWL.

7.1 Cement Treated Base

On the day of research a tidy work space is needed where a considerable amount of road base will be required. CTB is a product used in the formation of roads that is generally applied at 150 to 200mm thick as the last layer prior to asphalt. It is a road base material that has a range of rock sizes allowing good bonding of the aggregate gaining strong compaction. At least 300 tonnes of CTB is required for one study, this would allow an area of road 100 metres long by 9 metres wide by 0.150 metres deep to be tested. Three hundred tonnes is calculated from a conversion factor of 2.25 tonnes is equal to 1 cubic metre.

7.2 Access

Delivery of the road base material requires an organised work site with good access for large truck and dog trailers to come and dump the road base in the work area. Each load carry's around 40 tonnes of material showing the need for at least 8 trucks to come through the work site delivering CTB.

7.3 Machinery

A suitable grader is a must for the study to occur, ideally it would be a modern machine that is a John Deere, Volvo, or Cat variety. It will have the ability to place large quantities of CTB accurately over a large area. The machine needs to be reliable, manoeuvrable and safe. Blind spots on the grader need to be highlighted to everyone and minimised in size.

The grader has to be "Trimble Ready" and be fitted with a Trimble 3D Grade Control System called the GCS900 and be paired up with a Universal Total Station (UTS). "The GCS900 Grade Control System is a cutting edge earthmoving grade control system that puts design surfaces, grades and alignments inside the cab. The system uses GPS, GPS and laser, or construction total station technology to accurately position the blade or bucket in real time, significantly reducing material overages and dramatically improving the contractors productivity and profitability" (Trimble, 2013a).

7.4 Hardware required

The Trimble SPS930 or SPS730 Universal Total Station (UTS) is essential in the study. It will allow the surveyor to take control of all machine control requirements and provide accurate measurements in real time to the GCS900 system. The "UTS reliably tracks a machine target and passes the positioning information from the total station to earthmoving machinery as quickly and as accurately as possible. The machine operator can conduct real time fine grading operations to millimetre accuracy while minimising rework and increasing profits" (Trimble, 2013c). We will be using the SPS930 which "is accurate to one arc second in vertical and horizontal angles, making it ideal for fine grading operations where the accuracy tolerance is very tight (Trimble, 2013d) translated this is close to 1 millimetre (mm) vertical and 3mm horizontal accuracy over 100 metres (Trimble, 2013h). Trimble claims this machine to be the fastest and tightest accuracy total station on the market (Trimble, 2013d) so it has got to be ideal for recording consistent information in my research.

A Tripod is required for the Total Station to sit on in a cornered off area of the work site on stable ground. Bollards are required to be placed around the Total Station and Tripod. The Tripod needs to be checked for cracks or loose nuts and bolts.

7.5 Software required

Computer Software is required for survey results to be electronically recorded and for the different computers to talk to one another. On the grader, Grader Control System 900 (GCS900) software is used to run the height of the blade and talk via radio communication with the SPS930 UTS system. The surveyor needs access to Site Controller Software 900 (SCS900) to communicate with the UTS and be able to calculate its position and orientation prior to connecting the UTS with the Grader Control System. The SCS900 software has a range of surveying applications from measuring to stakeout to machine control connectivity. After the grader has recorded the final surface of the material he will disconnect from the UTS. I shall then connect using the SCS900 software and record the points with the range pole. These are then exported as a Microsoft Excel Comma Separated Values (csv) file ready to be imported into the preferred CAD program.

The SCS900 software is installed on a Trimble Handheld controller called a TSC3. Trimble.com describes “the controller as a ground-breaking handheld field computing solution that streamlines the flow of everyday surveying work and the number of peripheral devices you need in the field” (Trimble, 2010b). The controller will run the software and act as a storage device for all the required survey files design and as-constructed. It is shown in the image below (Sitech).

Figure 7-1 Trimble TSC3 Controller

Terramodel is a Civil Aided Design (CAD) package that allows the surveyor to process all the raw data collected in the field and turn it into a more useable format. “The software allows you to perform all the necessary Coordinate Geometry (COGO) calculations, quickly and easily produce roadway designs, generate contours, and calculate volumes” (Trimble, 2013e). I will use it to import the csv file generated from the SCS900 software and check this field information against the road alignments, surfaces and generate a conformance report showing the surface is within tolerance.

Also in use for this research project is another form of CAD software called Trimble Business Centre or TBC. The Trimble website claims that “Trimble Business Centre provides you with the capability to efficiently edit, process, and adjust your survey data with confidence” (Trimble, 2013f). It will be used to check the road alignment and surface prior to application in the field and to also produce a “svl” and “svd” file for the GCS900 software. The GCS900 requires these two file formats to run the correct heights and position in the field. The svl file is the line work strings. The svd file is the surface the grader will cut to.

Access to VisionLink is not required for the study to occur but would be beneficial. VisionLink provides near real-time equipment performance information for the grader being studied. Having access to this data helps in determining the profitability and productivity of the Machine Control technology. VisionLink access will help in number 2 in my project specification, evaluate current usage of machine guided graders with particular emphasis on survey accuracy.

Once the grader has recorded its finished surface level a “tag file” is produced which is compatible with two programs one being VisionLink and the other being Site Vision Office. Site vision office is a specialised survey software program used to export, import and convert survey files for ongoing use. Described on the Sitech website “The easy to use Trimble Site Vision Office software is the data management tool for the Site Vision GPS Machine Control system” (Sitech, 2013). I shall use this software to convert the tag file produced from the grader into a Terramodel “PRO” file which can be used in Terramodel.

8. Field Testing Landsborough Highway

In order to achieve objective 3 described at the start of this report:

#3. Conduct a study on the accuracy of a Trimble machine guided grader by comparing heights recorded from the grader to heights surveyed in the field.

The following steps will need to be performed

- Calibration of Trimble SPS930 total station and Trimble guided grader
- Record the finished surface using the blade of the grader and extract tag file
- Record the finished surface using the range pole at regular intervals
- Comparison of the two surfaces

Through my literature review I was unable to find any published reports on the direct comparison between heights recorded from the grader to heights surveyed in the field, so I knew that this part of the study will be particularly challenging. I was experienced with calibration of the grader, benching the grader and conforming the grader to ensure the finished product was within specification. But unfortunately this is where my experience and the majority of my work colleagues experience stopped. The challenge was I had to change the settings within the software to ensure the machine was recording when needed. The second substantial part of this stage was to extract a tag file or TIN from the grader that could be used for a direct comparison.

This chapter describes how the actual study occurred in the field. It takes a closer look at the finer details in the study. How my work colleagues and I took certain steps towards ensuring the highest accuracy possible from the equipment we had meanwhile guaranteeing consistency in the results. We also had a number of issues in the field, some of these I was able to find a solution for and some issues were beyond my control.

I was going to have to physically get access to a grader for a few hours at a time to conduct the study. This proved to be more difficult than I originally thought and was going to involve a lot of good talking, good timing and good luck. Then once access to the grader was given pressure was on immediately to ensure I was able to get the results needed.

8.1 Field Testing Landsborough Highway Barcaldine to Longreach 24th to 29th June

Field testing was on Seymour Whyte Constructions (SWL) Landsborough Highway Rehabilitation Project based out of Barcaldine in Central Queensland. SWL has teamed up with Bouygues Travaux Publics to deliver the project worth $61.4 million. The project will deliver extensive repair and rehabilitation works, including road reconstruction, shoulder reconstruction and pavement patching to the Landsborough Highway. At any one time the project would have up to ten Trimble guided graders on site using the Trimble GCS900 system. Half of these using UTS precision with either SPS930 or SPS730 Universal Total Stations guiding the blade to sub 5 millimetre accuracy. These sorts of numbers created the ideal site for field testing to occur.

As with a lot of construction work complications are likely to occur with factors outside of my control hindering what I was able to do on the Landsborough job. Things I needed to be mindful whilst on site was that I needed to cooperate with their daily production schedule. I was allowed to play with the grader that supported the stabilisation crew provided that production or quality was not affected. I was clearly told from the superintendent “that any reworked areas would cost the job $50k and that they were under tight schedules he did not want affected due to some hot shot university student trying to reinvent the wheel”. What it really boils down to is am I making money for the job and is my research effecting production.

So once all the finer details were sorted field testing was to be conducted on a CAT 140M Grader fitted with a Trimble 3D Grade Control System (GCS900). This modern machine combined with a good operator and a Trimble SPS930 Universal Total Station was ideal. The grader was fitted with a digital speed display and cruise control allowing a set speed to be established for final trimming. John the grader operator had the best reputation on site for taking pride in his work and being meticulous about the product he produced. John is very passionate about his grader and enjoyed having a bit of a play with the software to see what it is capable of doing.

The morning of the first field test came round and we had to ensure all the equipment was as accurate as possible prior to testing. So the Trimble SPS930 total station was calibrated along with the range pole and Trimble guided grader.

8.2 Calibration of the Trimble SPS930 Total Station

The Total Station needs to be calibrated around once a month or prior to doing any real accurate works to ensure precise results.

Parts of the total station that are checked during the calibration process include:

- Compensator Calibration
- Horizontal and Vertical Collimation test
- Trunnion axis tilt test
- Tracker collimation test (auto lock collimation)

A calibration was carried out on all of these adjustments the total station makes and stored within the machine

8.3 Calibration of the Surveyors Range Pole

Prior to benching the grader and before any measurements were made good survey practice is to be precise with the height of the range pole (target height). As wear and tear occurs on a pole it doesn’t always measure what it says it is. For example you may extend the pole to a height of 2.200m but is it actually that number. It could be up to 5mm out in either direction so we needed to measure the length of the pole at 2.200m with a tape measure. This had to be done with the point on the bottom and the flat bottom. The flat bottom is a flat foot that attaches to the bottom of the pole replacing the point. Its addition to the pole ensures the surface that is being measured is not penetrated and a true height is recorded. I used the flat bottom throughout all of the field testing to ensure accuracy of the results. A good surveyor needs to know the differences in height he is applying to the pole by changing from a point to a flat bottom.

So the pole was measured in both differing setups and a height recorded in my field book. Set at 2.200m the range pole with a point attachment measured 2.198m and with a flat bottom attached measured 2.202m a height difference of 4mm. In a lot of survey situations 4mm of difference in height is significant showing the importance of applying the correct height to the range pole.

8.4 Calibration of the Trimble guided grader

As mentioned in the methodology chapter the grader needs to be calibrated prior to field testing. And instructions to do so follow a number of key steps.

These steps include"

1. Park on a smooth hard surface
2. Remove wheel lean and articulation
3. Centre the A frame and blade
4. Rotate circle to square the blade
5. Position blade on the ground
6. Mark blade and tyre positions

So we positioned the grader on a relatively flat area ready to do a full mainfall, blade slope and rotation sensor calibration and followed through the above steps.

Figure 8-1 Trimble Guided Grader in Position 1 Landsborough Highway

After position one was recorded the grader was rotated 180° and moved into position 2 shown below.

Figure 8-2 Trimble Guided Grader in Position 2 Landsborough Highway

After pressing continue, readings are taken calibrating the blade slope sensor. The blade is then lifted allowing the grader to move forward so that the tyre marks move onto position 3. After pressing continue in position 3 the mainfall sensor is calibrated completing the process.

John and I did a few more checks after this, one of this was to check the verticality of the mast. He placed it in a vertical position as shown on his computer screen and I placed a spirit level on the mast to ensure he was correct. This process checked the blade pitch sensor.

8.5 Blade Wear

The cutting blade of a grader is one of the most important parts of the machine, as it's the cutting edge of the grader that does the final trimming. Part of the grader operator's job is to maintain the cutting blades of the machine through inspecting the blade for uneven wear and replacing the blade once it is worn. In addition to this a Trimble guided grader operator needs to regular measure the blade wear. A measurement is taken from the centre of the bolt to the cutting edge of the blade. John and I carried this out prior to testing and came up with a distance of 87mm. This is shown in Figure 5.8 and 5.9.

Figure 8-3 Measuring Blade Wear Landsborough Highway

Figure 8-4 Measuring Blade Wear Landsborough Highway

The 87mm measurement is then entered into the computer software

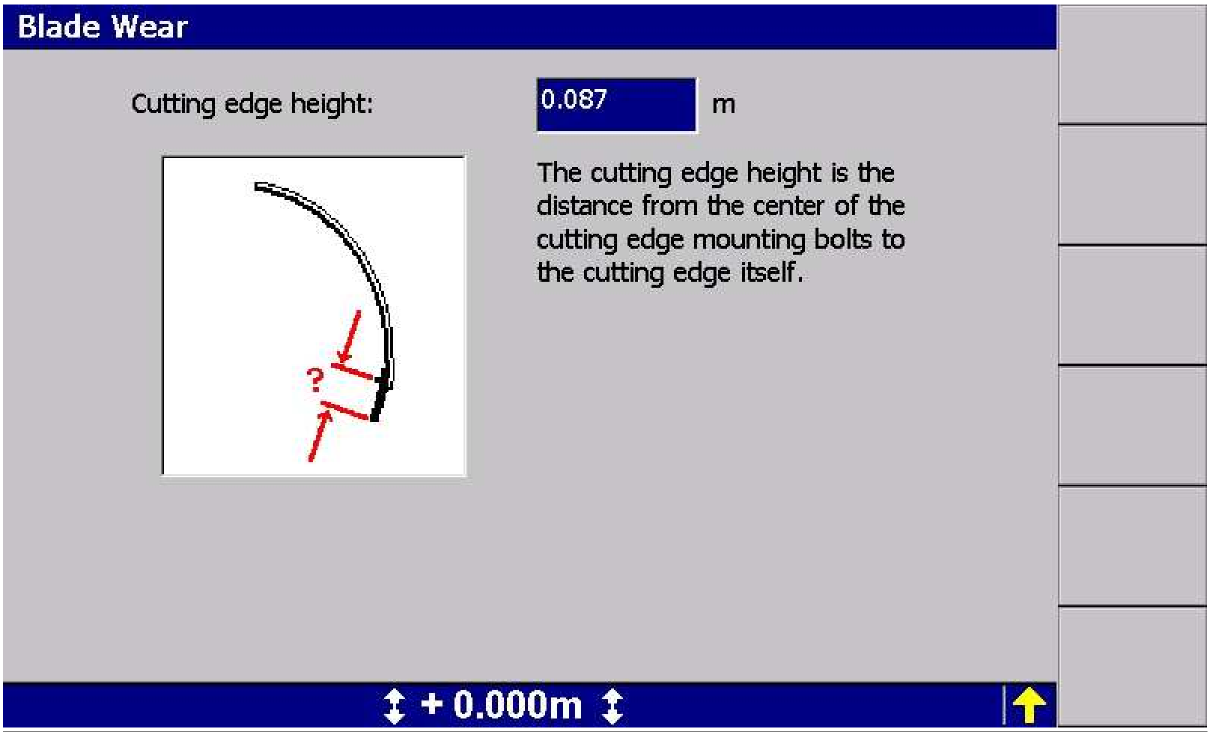

Figure 8-5 Entering Blade Wear into Software

Every morning when the operator runs through his pre start checks he needs to inspect the blade and measure the blade wear. As there are days where blade wear can be up to 20mm over the course of the day. Especially where final trimming has occurred the previous day on a very hard surface.

8.6 Trimble SPS930 Total Station Setup

In order for the Trimble SPS930 Total Station to provide accurate measurements to the Grader its position needs to be calculated and the instrument needs to be given an orientation. The modern way to do this is through a resection (or free station) by using two or more points. The resection has a strong advantage over other methods due to the fact that you do not have to setup over a known mark. The instrument can be placed anywhere provided that you can see two or more marks. Good practice when choosing an ideal spot for the instrument is to position the instrument between the two known marks. E.g. one control point to the north and one control point to the south. Choose a location that is off to one side of the main construction works, preferably higher ground giving the grader maximum capacity for unobstructed line of sight.

I choose the most ideal location for the instrument and resected in its position. Previously two known benchmarks had been placed in the ground at an easily accessible location for the grader and myself. I checked onto these confirming the total station position is correct.

8.7 Benching of the Trimble Guided Grader

In order for the grader to trim accurately to a final height it needs to be given a height from the instrument that is accurate and trustworthy. The recommended method for assigning this height is through benching the grader. The benching of a Trimble guided grader is a process by which you assign a known height to the grader in use. From then on all heights for the grader are in terms of the benchmark the machine was benched over. This applies to every new setup and when the grader moves from one area to the next. It is good practice also to ensure that the grader checks onto known benchmarks throughout the day to ensure nothing has changed within the grader and the total station is still sending accurate information to the grader.

Prior to our field testing the grader needed to be benched off a known survey benchmark. Two dumpy pegs were placed in the ground at distances of around 40 metres and 70 metres from the instrument. The reduced level assigned to these was checked once the total station has been setup ensuring a correct height.

For the purposes of this study it is essential that the grader and the surveyor's pole are benched off the same benchmark and adjusted appropriately. For example prior to doing any surveying with the range pole I checked onto the benchmark and if I got a difference in height to the assigned level of the benchmark I adjusted the pole height accordingly so that the elevation matched the elevation given to the benchmark. Ensuring I had the greatest opportunity possible to achieve my objective of comparing heights recorded from the grader to heights surveyed in the field. This step safeguarded against any possibility of bias getting included into the results.

John the grader operator was particular about his work and both of us worked as a strong team ensuring the grader was as accurate as we could get it prior to testing.

8.8 Speed of the Grader

In chapter 5 my Literature Review identified the need to monitor Latency, Speed and Distance to the moving target. All of these are related to a certain degree. This section will discuss the effect of varied speed on our Field Testing. How we reduced the opportunity for error and maximised the accuracy of the results.

In Field test 1 the grader was trialled at two speeds of 3.6km/h (or 1 m/sec) and 1.8km/h (0.5m.sec). This was in an attempt to gauge the impact of speed on the accuracy of the system. As the Trimble SPS930 total station produced increased vertical error to a moving target over a certain speed. The stated vertical error from Trimble mentioned in chapter 5.8 is +/-2mm+14ppm (parts per million) accuracy to a moving target at 1m/s (metre per second) (Trimble, 2013b). So I took this speed to be the maximum speed I will work with and then halved it in order to try and gauge an effect speed had on my results.

John took the suggestions for speed on well and ran over the surface twice in record mode at the two set speeds. The 3.6km/h speed worked better with the grader performing to its usual standard and surveying the surface. When John went for his second pass over the surface at 1.8km/h issues appeared with the practicality of this speed. It was too slow for the grader, so every time the grader ran over a little bump or mound in the surface the grader would lift up and over the bump instead of cutting straight through it. As the rev's were lower at 1.8km/h than at 3.6km/h the machine tendered to rise up and go over the surface taking the easier option.

Unfortunately it turned out that I was unable to extract the tag file from the grader after this survey was done. I was unsure of what went wrong so tried many times to download the tag file with no success. John even ran over the surface a second time at 1.8km/h still with no success. So a decision was made then and there that due to practicalities of running the grader at the slower speed that I would not pursue the 1.8km/h speed any further. My team of helpers would just focus on achieving some good consistent numbers at one set speed. Doing this increased my chances of achieving objective 3 “Conduct a study on the accuracy of a Trimble machine guided grader by comparing heights recorded from the grader to heights surveyed in the field”.

The 3.6km/h test worked reasonably well as the grader performed like it should running it’s blade smoothly and concisely over the surface. I managed to extract the “tag” file from the grader and download it into Site Vision Office (SVO). As I was under some time pressure I didn’t fully check the coverage of the tag file prior to surveying the surface with the range pole. This proved to be a mistake I could not rectify later as I only managed to record 18 points out of 40 surveyed on the surface that were within the boundaries of the graders survey. This is discussed further in the Obstacles in the Field Section next.

8.9 Obstacles in the Field

8.9.1 Setting the Grader to record whilst in automatic mode

In the days leading up to field testing it was never envisaged that it would be so difficult to extract the information from the grader. There were 4 days available on the job. The first two days were mainly all about familiarisation with the people, machinery and the location. This took some time as the job was 51km long and most people were interested in seeing me do setout work rather than concentrate on my field testing. On the third day I got my window of opportunity, a little bit of free time with the grader that is used for stabilisation. After calibrating the instrument and grader we could finally start moving some material prior to trimming. I was excited and stressed all at the same time as finally it was happening. The first issue was getting the machine into record mode which can be found in its settings. The box “record while mapping” needed to be ticked. The next hurdle was getting the machine to record whilst in automatic mode and produce a “tag” file. This took some time and it wasn’t until the couple of hours that was available to me on the last day that we finally cracked it. The machine needed to be on record while in automatic mode. We had the machine on record while in manual mode and were not getting the information out of it that I was after. This slight difference in settings was not picked up by myself or John. I was not in the cab with John I couldn’t see exactly what he was doing at all times and he was not on the phone to technical support. We were running a little bit of a system I was on the ground making phone calls to Sitech our technical support while John was in the cab recording the surface. After some hours and days had passed we finally managed to record the surface while in automatic mode. Automatic mode is where the hydraulics control the height of the blade and the operator just needs to drive the grader (mentioned in section 2.4). This delay and misunderstanding was very frustrating as it affectively took us four full days to get my first bit of information from the grader.

8.9.2 Width of the Surface

Discovering and interpreting the surveyed information proved to be difficult and yet another obstacle in the field. I have now managed to extract some information off the grader but don't know its quality and its boundaries. As time was of the essence I needed to carry on with the sampling collecting as much information as possible.

Field test 1 sample area comprised of a 190 metres long by 5 metres wide section of road that I managed to collect 39 surveyed points with the range pole. The road consisted of 2 lanes at 3.5 metres wide with a crown in the middle and a 1.5 metre shoulder. Spacing was every 10 metres on chainage starting 3.5 metres offset to the road crown then 1.5 metres and was due to be repeated on the opposite side giving 4 shots across the surface. Due to being controlled by production of the job we continued with the other side of the road prior to downloading the tag file and checking the data on the computer. This meant the grader had to push the excess material onto the side I had already surveyed covering up my sample points leaving no room for error. Once the other side of the road was prepared John was able to make a couple of passes across the surface recording the TIN for my studies. For some reason we were unable to produce a tag file again and widening the already created TIN in this instance was unachievable. At this point I was disappointed but not too worried as I had 39 surveyed points already on the surface above my target sample size of 30points.

Unfortunately it turned out later on that only 18 of the 39 surveyed points were usable and fell under the TIN created from the grader. For some reason the grader blade did not record the surface to its full profiled extent and I managed to run a line of sampled points just outside the TIN for the entire length of 190 metres. Yet another frustration to add to my tally, on the positive side I had some very accurate information and had made a start to the project

The below plot shows the extent of the TIN with the 39 surveyed point overlayed across the top

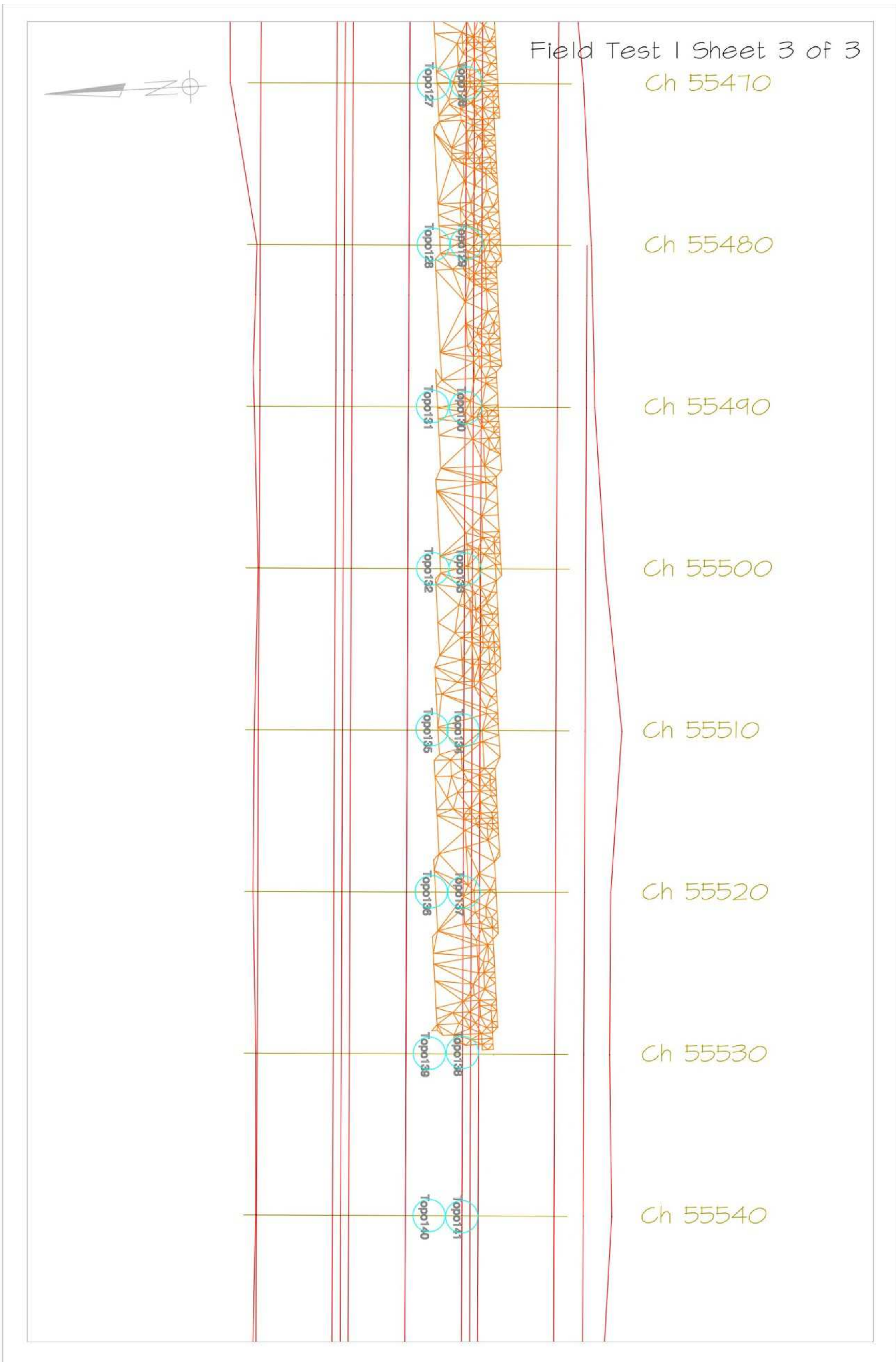

Figure 8-6 Triangulated Irregular Network halfway accross road surface

It turned out that not enough testing was achieved in this first week so the last couple of tests were left up to John Hartley and Anthony Mercer to complete without me.

Anthony managed to come through with the goods at the end of July with another field test using the same operator (John) and the same grader (CAT 140M). The second time round the team was not as confident in the data they produced with a different product used due to circumstances out of our control. The road base was more of a subgrade like material that didn't bind together as well as the previous field test. We still pursued the numbers and managed to get some results for analysis.

The sample site was 70 metres long by 8 metres wide. We collected 80 points over the area giving some good numbers to work with. The road consisted of 2 lanes at 3.5 metres wide with a crown in the middle and a 1.5 metre shoulder. The surface was sampled consistently and evenly across the whole area to ensure the most accurate sample. Spacing was every 5 metres on chainage starting 4 metres offset to the road crown then 2 metres then 0.5 metres and repeated on the opposite side giving 6 shots across the surface.

John calibrated the grader and ran the blade of the grader across the finished surface creating a TAG file or TIN to be extracted from the grader and downloaded into SVO and then later on exported into Terramodel. This time round the whole of the 80 points sampled occurred within the boundaries of the TIN. We had a large sample size with good intensity of points creating some accurate data with a smaller standard deviation than Field Test 1.

9. Results

In order to achieve the Project Aim;

To demonstrate the accuracy generated by a Machine Guided Grader blade.

Two individual tests were carried out on a Machine Guided Grader up on the Landsborough Highway job. The field testing was designed to achieve the objectives of this report and place a value on the accuracy of a Machine Guided Grader blade.

This Results section will show the numbers achieved for the two studies carried out on the Landsborough Highway job.

Tables shown will be:

Table of Constants used in the Testing

Results Table Field Test 1

Results Table Field Test 2

F- Test Testing the difference between Field Test 1 and Field Test 2

Table 9-1 Table of Constants Used

Test Number	**Date**	**Speed**	**System**	**Grader**	**Instrument**	**Operator**
Field Test 1	28/06/2013	3.6 km/h	GCS900	CAT 140M	SPS930 1”	John
Field Test 2	26/07/2013	3.6 km/h	GCS900	CAT 140M	SPS930 1”	John

9.1 Field Test 1

Results from Field Test 1 shows the average difference in height between the recorded surface and the surveyed points

Table 9.2 Results Field Test 1

Sample Population	n = 18
Sample Mean (metres)	x = 0.00028
Sample Standard Deviation (metres)	s = 0.00493
Sample Variance (metres)	s^2 = 0.00002

Field test 1 showed some very accurate results with an average difference in height from the recorded surface to the measured survey points at 0.0003M or 0.3mm. Unfortunately a large sample size was not achieved and only 18 recorded points fell within the boundaries of the TIN. Reasons for this are discussed further in chapter 10.5 Discussion on 3.7mm difference between Field Test 1 and Field Test.

9.2 Field Test 2

Results from Field Test 2 shows the average difference in height between the recorded surface and the surveyed points.

Table 9.3 Results Field Test 2

Sample Population	n = 80
Sample Mean (metres)	x = 0.00395
Sample Standard Deviation (metres)	s = 0.00362
Sample Variance (metres)	s^2 = 0.00001

Field test 2 showed a larger average difference in height from the recorded surface to the measured survey points at 0.00395M or 4mm. Results showed a substantially better sample size of 80 and a better standard deviation of 0.00362 compared to 0.00493. These differences prompted a need to see whether a significant difference occurred between the two studies.

9.3 F- Test Testing the difference between Field Test 1 and Field Test 2

In order to evaluate the two sets of results, further analysis was undertaken to test whether a difference occurs between Field Test 1 and Field Test 2. An F-Test will be conducted focusing on calculating an ANalysis Of VAriance or ANOVA. The ANOVA test makes a statistical comparison between the variances of the two data sets by incorporating the mean, variance and sample size.

The hypotheses for the F-test are:

H_o: There is no differences between the two variances

H_a: Larger variance Field Test 1 is significantly different than the smaller variance Field Test 2

Table 9.4

F-Test Two-Sample for Variances Alpha = 0.05 95%

	Field Test 1	*Field Test 2*
Mean	0.000278	0.003950
Variance	2.433E-05	1.309E-05
Observations	18	80
df	17	79
F	1.859233	
P(F<=f) one-tail	0.034588	
F Critical one-tail	1.753656	

The calculated F Value 1.859 is greater than the critical F Value of 1.754 so we are 95% confident that there is a difference between the two variances tested.

We therefore accept Ha: Larger variance Field Test 1 is significantly different than the smaller variance Field Test 2

Table 9.5

F-Test Two-Sample for Variances Alpha = 0.1 90%

	Difference	*Difference*
Mean	0.000278	0.003950
Variance	2.433E-05	1.309E-05
Observations	18	80
df	17	79
F	1.859233	
P(F<=f) one-tail	0.034588	
F Critical one-tail	1.547276	

The calculated F Value 1.859 is greater than the critical F Value of 1.547 so we are 90% confident that there is a difference between the two variances tested.

We therefore accept Ha: Larger variance Field Test 1 is significantly different than the smaller variance Field Test 2

Table 9.6

F-Test Two-Sample for Variances Alpha = 0.01 99%

	Difference	*Difference*
Mean	0.000278	0.003950
Variance	2.433E-05	1.309E-05
Observations	18	80
df	17	79
F	1.859233	
P(F<=f) one-tail	0.034588	
F Critical one-tail	2.202363	

The calculated F Value 1.859 is less than the critical F Value of 2.202 so we are not 99% confident that there is a difference between the two variances tested.

We therefore accept Ho: There is no differences between the two variances

Comments

The two field test were tested on a different type of road formation. Field test 1 was a stabilisation type of material. Field test 2 was a sub base type of material.

10. Discussion

In the Implications and Consequential effects chapter section 6.1 it was identified that success for SWL in this project would be proving that the grader can achieve results accurate to 5mm or less.

In order to achieve results of 5mm or less whilst achieving the highest accuracy possible on a Trimble Guided Grader much thought and consideration had to be included into data production. The Landsborough Highway job was an ideal site for all Field testing to occur but was going to be useless if carried out in the wrong way.

In order to accomplish simplistic non bias results when defining the accuracy of a Machine Guided Grader particular steps needed to be taken. The ideas used to create the environment I was looking for are mentioned in the Methodology and Field Testing Landsborough Highway chapters. But why was this approach needed? Why did I bench off exactly the same benchmark? Why was it important to use the same operator for all field testing? This chapter will discuss these thoughts along with the results produced from the two Field Tests that were carried out on the Landsborough Highway job.

10.1 Importance of Equipment and Calibration

In order to achieve results with a close relationship between the grader and surveyors range pole the equipment used needs to be of the highest quality and be well maintained to achieve accurate results. Calibration of the grader and the SPS930 Total Station ensured consistency between the two sets of data. As both field tests were carried out a month apart this gave opportunity for error in the results and some sort of bias creeping in. By calibrating the equipment prior to testing we are giving ourselves the best chance possible.

On top of calibration I also ensured that the same grader was used in both field tests and the same specification of instrument. So a CAT140M and a SPS930 1” instrument was used in both field tests to ensure consistency.

By doing all of this I kept the opportunity for errors in the results at an absolute minimum and further promoted strength in the findings.

10.2 Importance of operator

In construction many people always talk and recommend good operators in all fields. Whether it be a truck driver, a drill rig operator or a grader operator all of the “good” operators tend to just take a little bit of extra care. They take pride in their work and are concerned about their reputation. In general the operators are usually contractors to the job and should be concerned about where there next pay check is coming from. So it is in their best interests to do a great job cementing their position within the team.

In this study I managed to use this to my advantage. John, the operator with the best reputation on site got recommended to me as he was quite methodical in his task, took new ideas on well and was willing and patient. Something that I needed so was grateful in working with him. By using John in both field tests it meant that all of the learning’s from field test 1 would be carried over to field test 2 promoting further consistency between the results.

10.3 Importance of using the same benchmark and the same setup

Prior to all accurate works being carried out, the grader always needs an elevation applied to the machines blade. This process is described in Chapter 5.3 called “Benching the grader”. Now for the best results possible it is vital that we use the same benchmark for the grader as we use for the range pole. If it differs by even 1mm the pole height needs to be adjusted to ensure the same reduced level is shown with the range pole. This is probably one of the most important steps in the whole process. As if an error of 2mm went undetected here it will be carried right through to the finished results. So we could have ended up with a 0.3mm difference and a 6mm difference instead of a 0.3mm and 4mm difference. The numbers are already very small just due to the nature of the study so 2mm of error is almost 50% of the difference between the two studies.

Also of particular importance to this study is using the same setup for both the grader and the range pole results. By doing this it not only ensured easy changing between the grader and range pole but also meant that the coordinates produced in both trials came from exactly the same origin. The control points used in the resection to calculate the Total Station's position were the same and all recorded points and surfaces are produced from exactly the same position.

Once all of these points of interest including the equipment, calibration, operator, benchmark and setup are all aligned correctly it was time to start testing the graders recording ability. Ensuring these steps occurred assisted the results in becoming very accurate and steered this research project towards two of the three objectives which were to;

2. Evaluate current usage of machine guided graders with particular emphasis on survey accuracy.

3. Conduct a study on the accuracy of a Trimble machine guided grader by comparing heights recorded from the grader to heights surveyed in the field.

10.4 Vertical error in Benching

At the start of the job prior to the grader arriving benchmarks need to be placed to bench the graders blade off and apply a height. This is a step that adds opportunity for error to the whole process so understanding is necessary as to where these errors are and how to minimise them. Mentioned in the previous section is the importance of the range pole and calibration of all equipment.

What has not been mentioned is the repeatability of creating exactly the same reduced level over a benchmark consistently time and time again. In an ideal world no matter how many times I visit the benchmark it would always say 104.555M. This does not always occur in the real situation as differences are known to occur. These differences were not studied within this study so I basically had to rely on the manufacturers specifications. The stated vertical accuracy from Trimble is 1” (Trimble, 2013b) for the SPS930 which is only 0.5mm over 100 metres.

For ease of use and simplicity I have decided to leave this opportunity for error out of my calculations and will present the data as if there was no error.

10.5 Discussion on 3.7mm difference between Field Test 1 and Field Test 2

Once testing was finished analysis of the results occurred to gauge the success of the project. In both tests a mean was produced that showed the mean difference between the two methods of recording the surface. Field test 1 showed a mean difference between the two surfaces of just 0.3mm and a standard deviation of 4.9mm. Field test 2 showed a mean difference of 4mm and a standard deviation of 3.6mm. Field test 1 only had a sample size of 18 and field test 2 had a sample size of 80.

Some differences were found between the two sets of information. Sample size varied quite a bit, the means differed a little and so did the standard deviations. But by how much did they differ and is this really an issue? Ideally more sampling would occur that has the same sample size and is of a similar road base material to really put a definitive measure of accuracy on the grader studied. Unfortunately this is the real world and not everything goes according to plan so I have to adapt my statistics to incorporate the results obtained in the field.

Through research and consultation we have come up with the most appropriate test for the results. The F-Test tests the variances between Field Test 1 and Field Test 2 by making a statistical comparison between the variances of two data sets. Calculating an ANOVA or ANalysis Of VAriance is essentially what is happening and one of the requirements for ANOVA is that "there should be no difference between the variance of the data sets". If a difference is then found through using the test, it can be assumed that the means of the data sets are different (Leicester, 2000).

The test is setup with two hypotheses.

The hypotheses for the F-test are:

H_o: There is no differences between the two variances

H_a: Larger variance Field Test 1 is significantly different than the smaller variance Field Test 2

So if the calculated value is greater than the critical value we must reject H_o at the chosen level of confidence and accept H_a (Leicester, 2000). In Table 9.4 the F-Test two sample for variances test showed a calculated value of 1.859 against a critical value of 1.754 at the 95% confidence interval. This means that we can say with 95% confidence that there is a difference between the two variances tested.

The critical value was also calculated at 90% and 99% confidence levels. Table 9.6 showed a calculated value of 1.859 and a critical value of 2.202 suggesting that we would have to accept the hypothesis that there is no difference between the two variances at the 99% confidence level. This was just a secondary measure at 99% to see exactly where the critical value would sit. For the purposes of this report I shall use the 95% confidence level test and conclude that a difference does exist between the two variances tested.

What we do know about Field Test 1 and Field Test 2 is that Field Test 1 was conducted on a stabilised road base material that is a mixture of cement and fine gravels. The product produced binds together quite well and is easily worked around with the grader to create a smooth even surface as shown in the photo below.

Figure 10-1 Field Test 1 Finished Surface Level

When Field Test 2 was conducted the product produced was more of a subgrade like material that didn't bind together as well so the opportunity for a smooth even surface was not quite as good. Unfortunately I don't have a photo showing this surface so differences can't be compared directly.

Results from the two surfaces and comments from the operator suggest that yes there was a difference between the two Field Tests and I accept this and talk further about it in the report's conclusion.

10.6 Tolerances on the Road Surface

Construction sites today are bound by positional, dimensional and relative position tolerances that have a purpose to ensure the product produced is durable, fits together well and is of a high quality. During the construction of a road many layers are bound together in differing thicknesses to gain optimum strength and durability. These layers have certain tolerances placed on them for quality control purposes. During both of our Field Tests the tolerances for height were +/- 15mm. This is a specification tolerance assigned to the principal contractor from the client. In our case the client was the Department of Transport and Main Roads (DTMR) who oversaw the job and ensured we met the specifications assigned for each section of the road.

In both of my Field Tests conducted the finished surface came within the required specification. The below tables show an average difference to design, a range, and a maximum and minimum.

Table 10.1 Range of Field Test 1

Count	18
Mean (metres)	0.000278
Maximum difference to design (metres)	0.013
Minimum difference to design (metres)	-0.005
Range (metres)	0.018

Table 10.2 Range of Field Test 2

Count	80
Mean (metres)	0.003950
Maximum difference to design (metres)	0.013
Minimum difference to design (metres)	-0.005
Range (metres)	0.018

There are a few points to consider when investigating both of these tables. Firstly there are three numbers which are exactly the same, the maximum, the minimum and the range. This suggests that some sort of relationship in fact does exist between the two tests even though the F-Test suggests a significant difference occurs between the two variances.

The range of 18mm for both studies suggests that the tolerances allowed of +/-15mm (a range of 30mm) is quite achievable and some tightening of this would not be an issue. The maximums occurring close to the specified maximum of +15mm and the minimums occurring closer to zero than the minimum of -15mm would suggest that the grader operator is pushing the limits of the system. Also the average difference between the graders surface and the range pole is either 0.3mm or 4mm in both cases a positive number.

The range, the maximum, the minimum and the mean are all sitting in the positive end of each of their respective areas. What this suggests is that there is a gap between the graders blade and the FSL of between 0.3mm on Field Test 1 and 4mm on Field Test 2. So in certain areas whilst the operator is running over the surface the blade is not always in direct contact with the ground. This is why the results are towards the positive end of the scale as all I have compared is results from the surveyed surface directly with the recorded TIN from the graders blade.

What this means is that opportunities do exist in tightening of the tolerances required from the client. It could be a valid answer in ensuring that +/- 15mm is achieved. Further studies in this area just need to prove that a properly calibrated Trimble Guided Grader can produce a surface that is within 4mm of the actual surveyed surface. This would give the client confidence in reducing the tolerances to +15mm -11mm and allow the principal contractor to produce conformance reports directly off the blade of the grader. This means that in a situation where the surface is -11mm below design on the graders report it would be no less than -15mm on the surveyors report based on the assumption that the gap between the blade and the surface is no larger than 4mm.

11. Conclusion

11.1 Conclusion

The aim of this project is to demonstrate the accuracy generated by a Machine Guided Grader blade whilst aligning three key objectives of the study with the aim in order to gain insight into a Machine Guided Grader.

The three key objectives were to:

1. Research machine guided graders used within Australia's construction industry.
2. Evaluate current usage of machine guided graders with particular emphasis on survey accuracy.
3. Conduct a study on the accuracy of a Trimble machine guided grader by comparing heights recorded from the grader to heights surveyed in the field.

These objectives provided direction for the author and ensured that some definitive results would be produced in the Results and Discussion section. The results shown in this section gave me confidence to conclude that the accuracy generated from a machine guided grader blade was demonstrated to within 4mm of the actual surveyed surface. Both studies conducted within this report show on average a difference of 4mm or better which is very good and has the ability to create further opportunities in use of the technology.

The report identified five key players in Machine Guided Graders used within Australia's construction industry which were Leica, Trimble, Topcon, Caterpillar and Prolec. Our emphasis was to focus on the Trimble Guided Grader.

Objective two was investigated and proven that current usage of machine guided graders is mainly for road formation and constructing a surface that conformed to standards set out by the client. The required tolerances were thought to be tight at +/- 15mm but the author identified opportunity within this range to further tighten the tolerance. Grounds for this were shown in both Field Tests with a range of just 18mm when the allowed range specified from the client was 30mm.

In conjunction with this the author recommends that with further education of the capabilities of a Trimble Guided Grader to a client like DTMR that the tolerances be reduced to +11 -15mm on a conformance report that is produced directly from the Graders Blade.

Provided that the principal contractor can show three things:

1. Show that the graders blade is accurate to within 4mm of the actual surveyed surface.
2. The principal contractor needs to show that a qualified Surveyor has signed off on this conformance report.
3. Show that spot checks were made at a specified interval (e.g. every 200 metres) on every layer from a qualified Surveyor using the traditional method of surveying the surface with a range pole.

Objective three was tested with a study conducted on the accuracy of a Trimble machine guided grader by comparing heights recorded from the grader to heights surveyed in the field. This particular study showed on average a difference of up to 4mm in height on the surface generated from the graders blade to the individually surveyed points. The results showed differences in the variances for both the tests indicating the need to reject the hypothesis H_o. The rejection of H_o suggests that there is a difference between the two variances which is accepted within this report. Even though evidence does show a difference between the two Field Tests the author still indicates that opportunities exist with conformance reports and tolerances. This has been given credit as a 4mm error in the report generated from the Graders Blade can be incorporated into the +/- 15mm tolerance by reducing it to +11 -15mm. All we are dealing with here is a difference of 4mm between the two Field Tests. So arguably this difference is very small and would not have an effect on the finished surface of the road.

11.2 Further Research

The research generated from this study has identified a window of opportunity in the recording ability of a Machine Guided Graders blade. Many different benefits have been identified with the use of this technology. It is now up to further researchers and construction companies to take this information and develop it further. Future research in the field of Machine Guidance and Automation would involve doing further testing on the accuracy of the conformance report generated from the Grader. This would give confidence amongst the industry in the new technology ensuring a fail-safe method was achieved.

Further education of the industry into what capabilities the machine has would be of particular importance also. As for the method of producing a conformance report from the blade of the grader it is essential for clients like the DTMR to accept it before we can use it.

Research in this field is evolving everyday so it is up to us as the user to ensure it is used to its fullest potential.

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13. Appendix A

Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/4112 Research Project

Project Specification

FOR:	Mitchell Bell
TOPIC:	**Accuracy of a Machine Guided Grader**
SUPERVISOR:	Dr Albert Kon-Fook Chong, Senior Lecturer, University of Southern Queensland
	Tom Williams, Survey Manager, Seymour Whyte Constructions Ltd.
SPONSORSHIP:	Seymour Whyte Constructions Ltd.
PROJECT AIM:	To determine the accuracy generated from a Machine Guided Grader blade.
PROGRAMME:	Revision 1 13/03/2013

1. Research Machine Guided Graders used in Australia's Construction Industry.
2. Evaluate current usage of Machine Guided Graders with particular emphasis on survey accuracy.
3. Conduct a study on the accuracy of a Trimble Machine Guided Grader by comparing heights recorded from the grader to heights surveyed in the field.
4. Produce graphs and tables that show the analysis clearly and accurately.
5. Produce a defined millimetre accuracy of the grader studied.

Agreed Mitchell Bell Date

______________________________ (Student) ____________________________

Dr Albert Chong Date

______________________________ (Supervisor) ____________________________

14. Appendix B

Field Test 1 Raw Data

Station Setup

Plot showing TIN vs Surveyed Points

Raw Data

Seymour Whyte Constructions
14/2404 Logan Rd
Eight Mile Plains, QLD
Ph +61 7 33404800
Monday, 29 July 2013 12:35:27 PM

PROJECT: ndsborough\Terramodel\Landsborough 2 (121217) TW (MC02) 130727 Uni.pro
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Design DTM is TTM1
Stripping applied to design is 0.000
Elevation difference is Pt's Elevation minus Interpolated DTM Elevation

Point Number	Easting	Northing	Elev	Design Elev	Difference	Tol	Name
Topo103	269495.030	7397545.514	251.017	251.004	0.013	++	PSHT
Topo104	269495.076	7397547.579	251.077	*	*		PSHT
Topo105	269485.178	7397548.061	250.970	*	*		PSHT
Topo106	269474.988	7397546.711	250.802	250.800	0.002	++	PSHT
Topo107	269475.146	7397548.643	250.871	*	*		PSHT
Topo108	269465.093	7397549.284	250.774	*	*		PSHT
Topo109	269465.075	7397547.667	250.718	250.721	-0.003		PSHT
Topo110	269455.202	7397548.317	250.636	250.631	0.005	++	PSHT
Topo111	269455.213	7397550.227	250.694	*	*		PSHT
Topo112	269445.260	7397550.893	250.615	*	*		PSHT
Topo113	269445.102	7397548.802	250.542	250.547	-0.005		PSHT
Topo114	269435.246	7397549.434	250.480	250.478	0.002	++	PSHT
Topo115	269435.290	7397551.433	250.544	*	*		PSHT
Topo116	269425.233	7397552.027	250.479	*	*		PSHT
Topo117	269425.244	7397550.024	250.415	250.416	-0.001		PSHT
Topo118	269415.315	7397550.540	250.357	250.353	0.004	++	PSHT
Topo119	269415.358	7397552.562	250.424	*	*		PSHT
Topo120	269405.353	7397553.101	250.374	*	*		PSHT
Topo121	269405.135	7397551.140	250.311	250.316	-0.005		PSHT
Topo122	269395.265	7397551.651	250.271	250.270	0.001	++	PSHT
Topo123	269395.333	7397553.673	250.339	250.330	0.009	++	PSHT
Topo124	269385.322	7397554.262	250.310	*	*		PSHT
Topo125	269385.196	7397552.217	250.238	250.242	-0.004		PSHT
Topo126	269375.275	7397552.772	250.217	250.220	-0.003		PSHT
Topo127	269375.349	7397554.820	250.286	*	*		PSHT
Topo128	269365.405	7397555.348	250.269	*	*		PSHT
Topo129	269365.365	7397553.296	250.203	250.207	-0.004		PSHT
Topo130	269355.232	7397553.878	250.202	250.202	0.000	++	PSHT
Topo131	269355.416	7397555.921	250.269	*	*		PSHT
Topo132	269345.391	7397556.428	250.261	*	*		PSHT
Topo133	269345.255	7397554.444	250.195	250.196	-0.001		PSHT
Topo134	269335.329	7397555.087	250.198	250.200	-0.002		PSHT
Topo135	269335.477	7397556.991	250.260	*	*		PSHT
Topo136	269325.454	7397557.572	250.252	*	*		PSHT
Topo137	269325.312	7397555.560	250.192	250.195	-0.003		PSHT
Topo138	269315.442	7397556.171	250.194	*	*		PSHT
Topo139	269315.495	7397558.215	250.259	*	*		PSHT
Topo140	269305.473	7397558.759	250.254	*	*		PSHT
Topo141	269305.300	7397556.744	250.189	*	*		PSHT

Average height difference is 0.0004
RMS (Root Mean Squared) is 0.0048
Mean is 0.0004 with Standard Deviation of 0.0049
44.444% above tolerance
55.556% within tolerance
0.000% below tolerance
End of Report

Field Test 1 Setup Location

Open WO	Work Order Name	130628 MC02 CH 55 CH 60
Open WO	Date	28/06/13
Open WO	Time	9:44:33 AM
Open WO	Operator Name	MITCH
Open WO	Site	MC02 Ch 60 Ch 70
Open WO	Primary Design (1)	130627 Ch 55-60 Ilfra V11
Open WO	Underlying Design (2)	
Open WO	Program Version	2.92 Build 8

Instrument Connection	Instrument Type	Trimble SPS930 1/1
Instrument Connection	Serial Number	72611231
Instrument Connection	Hz Angle Accuracy	1"
Instrument Connection	Vt Angle Accuracy	1"
Instrument Connection	DR Single EDM Accuracy	3 mm + 2 ppm
Instrument Connection	DR Tracking EDM Accuracy	4 mm + 2 ppm
Instrument Connection	IR Single EDM Accuracy	3 mm + 2 ppm
Instrument Connection	IR Tracking EDM Accuracy	4 mm + 2 ppm

Averaging Mode	Date	28/06/13
Averaging Mode	Time	9:48:03 AM
Averaging Mode	Number of Sets	1
Averaging Mode	Angle Tolerance	0°00'05"
Averaging Mode	Distance Tolerance	0.025 m
Averaging Mode	Turn On Autolock	Yes

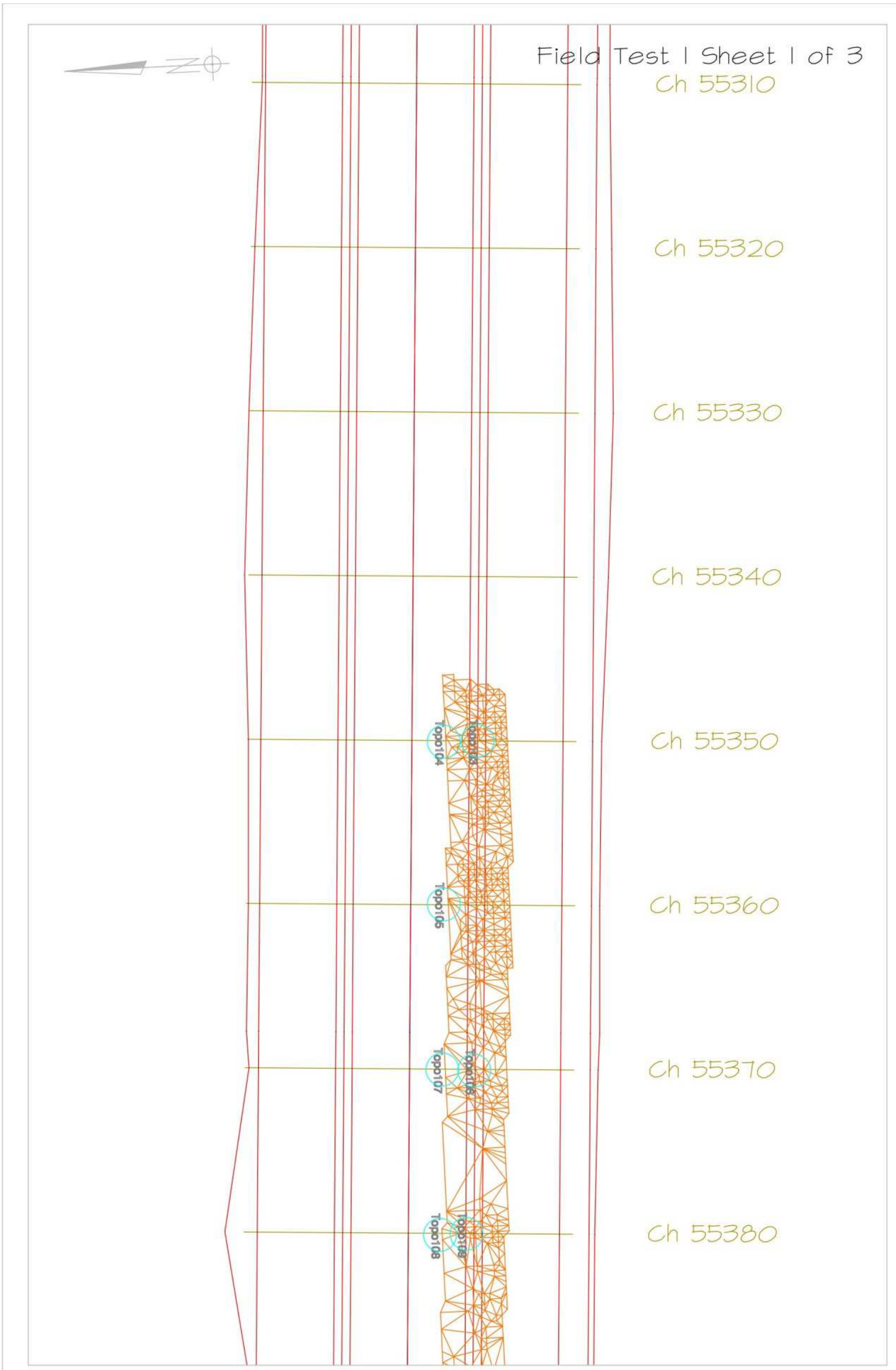
Averaging Mode	Date	28/06/13
Averaging Mode	Time	9:51:34 AM
Averaging Mode	Number of Sets	1
Averaging Mode	Angle Tolerance	0°00'05"

Averaging Mode	Distance Tolerance	0.025 m
Averaging Mode	Turn On Autolock	Yes

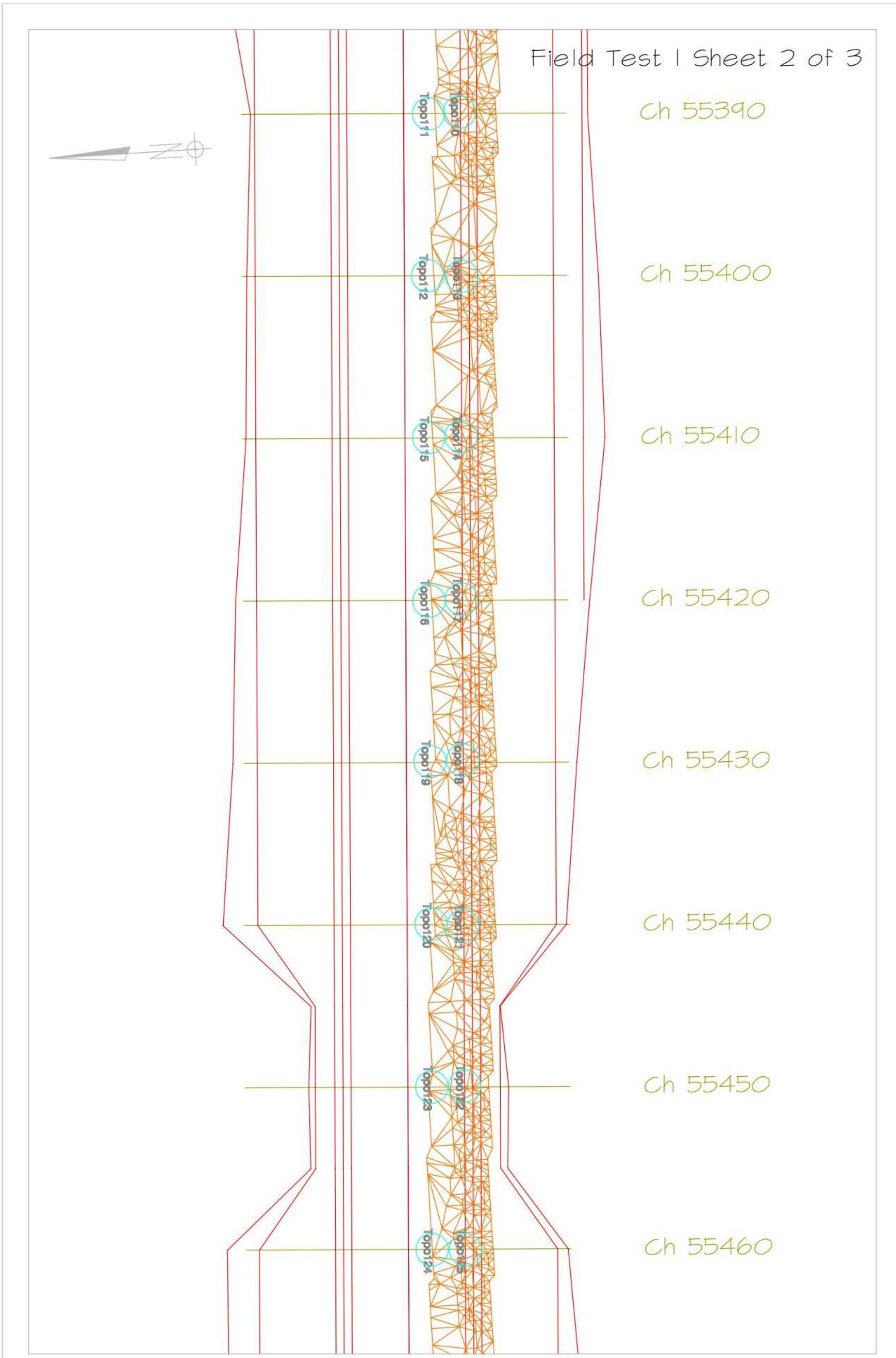
Instrument Setup	Date	28/06/13
Instrument Setup	Time	9:52:04 AM
Instrument Setup	Control Point Name	55250L
Instrument Setup	Control Point Name	55500L
Instrument Setup	Precision-Horz	0.022 m
Instrument Setup	Precision-HA	0°00'00"
Instrument Setup	Precision-Dx	0.022 m
Instrument Setup	Precision-Dy	0.002 m
Instrument Setup	Precision-Dz	0.002 m
Instrument Setup	Instrument Point Name	---
Instrument Setup	Instrument Type	Trimble SPS930 1/1
Instrument Setup	Instrument height	0.000 m
Instrument Setup	E of position	269467.356 m
Instrument Setup	N of position	7397517.566 m
Instrument Setup	Elv of position	252.738 m
Instrument Setup	Scale Factor	1.000000

Distance Corrections	Date	28/06/13
Distance Corrections	Time	9:52:05 AM
Distance Corrections	Apply Mean Sea Level(MSL) Corrections	No
Distance Corrections	Apply Scale Factor	No

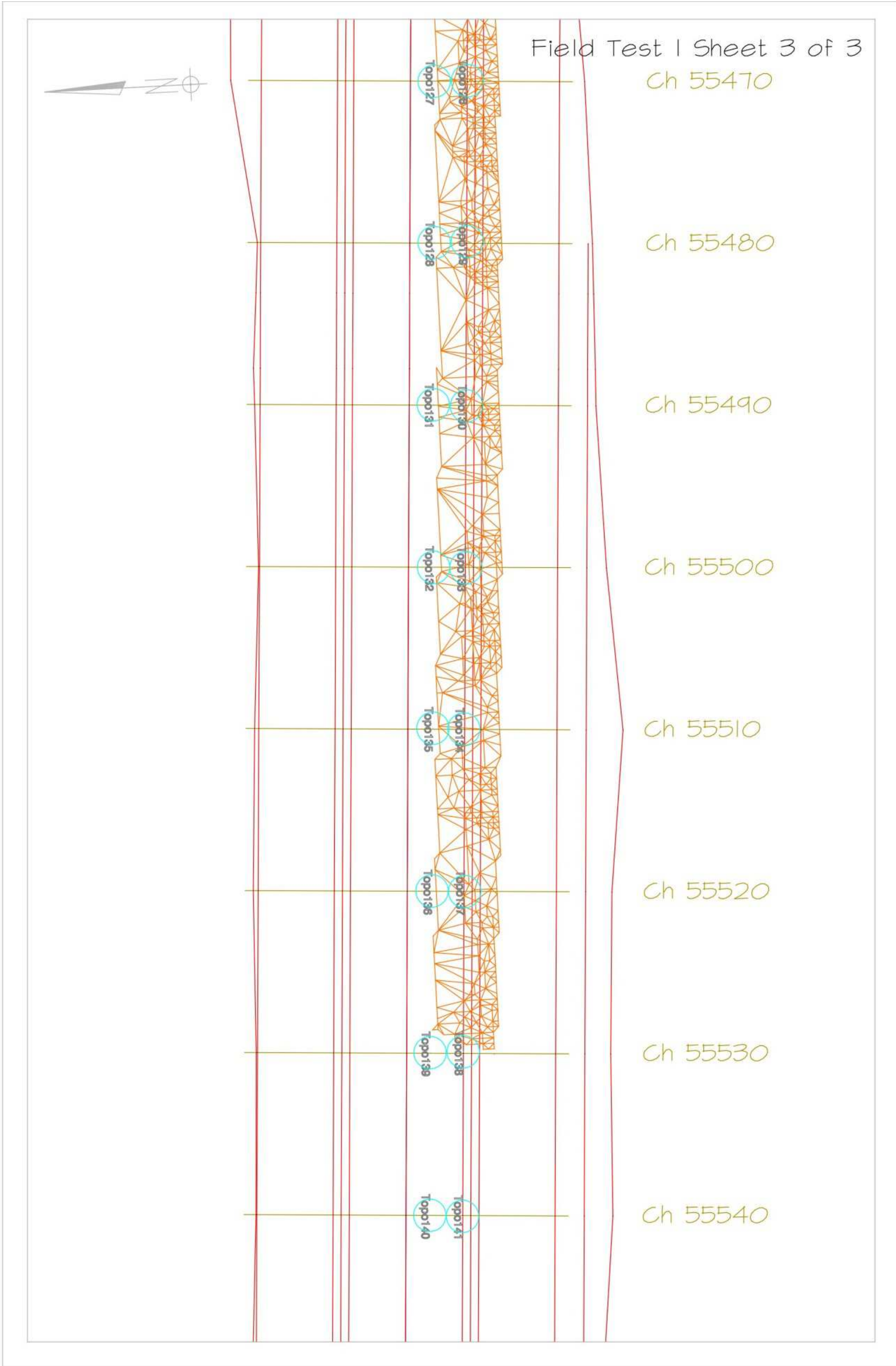
Plot showing TIN vs Surveyed Points



Plot showing TIN vs Surveyed Points



Plot showing TIN vs Surveyed Points



15. Appendix C

Field Test 2 Raw Data

Station Setup

Plot showing TIN vs Surveyed Points

<u>Raw Data</u>

Seymour Whyte Constructions
14/2404 Logan Rd
Eight Mile Plains, QLD
Ph +61 7 33404800
Friday, 18 October 2013 3:35:47 PM

PROJECT: ndsborough\Terramodel\Landsborough 2 (121217) TW (MC02) 130727 Uni.pro
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Design DTM is TTM1
Stripping applied to design is 0.000
Elevation difference is Pt's Elevation minus Interpolated DTM Elevation

Point Number	Easting	Northing	Elev	Design Elev	Diff	Tol	Name
359892	265746.821	7397631.951	236.680	*	*		SG
359893	265747.060	7397633.962	236.617	236.611	0.006		SG
359894	265747.411	7397635.405	236.572	236.571	0.001		SG
359895	265747.575	7397636.427	236.546	236.551	-0.005		SG
359896	265747.861	7397637.870	236.503	236.496	0.007		SG
359897	265748.209	7397639.897	236.437	*	*		SG
359898	265743.405	7397640.747	236.370	236.373	-0.003		SG
359899	265742.976	7397638.810	236.432	236.429	0.003		SG
359900	265742.702	7397637.272	236.477	236.475	0.002		SG
359901	265742.557	7397636.265	236.508	236.501	0.007		SG
359902	265742.198	7397634.773	236.551	236.541	0.010		SG
359903	265741.840	7397632.805	236.609	236.606	0.003		SG
359904	265736.934	7397633.753	236.553	236.540	0.013		SG
359905	265737.306	7397635.722	236.491	236.487	0.004		SG
359906	265737.482	7397637.185	236.446	236.445	0.001		SG
359907	265737.804	7397638.224	236.418	236.408	0.010		SG
359908	265738.067	7397639.645	236.371	236.368	0.003		SG
359909	265738.388	7397641.660	236.308	236.306	0.002		SG
359910	265733.471	7397642.529	236.265	236.263	0.002		SG
359911	265733.219	7397640.615	236.327	236.326	0.001		SG
359912	265733.054	7397639.081	236.382	236.387	-0.005		SG
359913	265732.736	7397638.107	236.405	236.399	0.006		SG
359914	265732.301	7397636.676	236.446	236.444	0.002		SG
359915	265731.872	7397634.661	236.507	236.502	0.005		SG
359916	265727.036	7397635.607	236.461	236.465	-0.004		SG
359917	265727.393	7397637.621	236.407	236.404	0.003		SG
359918	265727.730	7397639.104	236.362	236.356	0.006		SG
359919	265727.921	7397640.110	236.330	236.328	0.002		SG
359920	265728.158	7397641.599	236.279	236.283	-0.004		SG
359921	265728.625	7397643.552	236.222	236.223	-0.001		SG
359922	265723.670	7397644.406	236.201	236.202	-0.001		SG
359923	265723.346	7397642.505	236.260	236.256	0.004		SG
359924	265723.119	7397641.034	236.307	236.303	0.004		SG
359925	265722.874	7397640.005	236.340	236.337	0.003		SG
359926	265722.556	7397638.492	236.385	236.381	0.004		SG
359927	265722.195	7397636.573	236.451	236.445	0.006		SG
359928	265717.222	7397637.586	236.438	236.429	0.009		SG
359929	265717.606	7397639.490	236.369	236.365	0.004		SG
359930	265717.895	7397640.993	236.329	236.329	0.000		SG
359931	265718.057	7397642.008	236.297	236.293	0.004		SG
359932	265718.400	7397643.497	236.253	236.250	0.003		SG
359933	265718.764	7397645.439	236.194	236.190	0.004		SG
359934	265713.332	7397646.506	236.197	236.192	0.005		SG
359935	265712.957	7397644.551	236.256	236.255	0.001		SG
359936	265712.709	7397643.056	236.302	236.298	0.004		SG

359937	265712.468	7397642.086	236.331	236.326	0.005	SG
359938	265712.242	7397640.559	236.379	236.375	0.004	SG
359939	265711.749	7397638.628	236.440	236.434	0.006	SG
359940	265706.875	7397639.612	236.458	236.450	0.008	SG
359941	265707.266	7397641.578	236.391	236.389	0.002	SG
359942	265707.609	7397643.023	236.351	236.345	0.006	SG
359943	265707.770	7397644.047	236.320	236.318	0.002	SG
359944	265708.102	7397645.536	236.273	236.269	0.004	SG
359945	265708.462	7397647.537	236.209	236.206	0.003	SG
359946	265703.571	7397648.444	236.245	236.239	0.006	SG
359947	265703.201	7397646.489	236.307	236.302	0.005	SG
359948	265702.890	7397645.028	236.351	236.347	0.004	SG
359949	265702.671	7397643.992	236.382	236.374	0.008	SG
359950	265702.438	7397642.539	236.424	236.422	0.002	SG
359951	265701.998	7397640.586	236.488	236.478	0.010	SG
359952	265697.116	7397641.566	236.529	236.524	0.005	SG
359953	265697.486	7397643.519	236.462	236.462	0.000	SG
359954	265697.778	7397645.001	236.419	236.416	0.003	SG
359955	265698.273	7397647.443	236.344	236.337	0.007	SG
359956	265698.685	7397649.427	236.286	236.283	0.003	SG
359957	265693.772	7397650.377	236.339	236.333	0.006	SG
359958	265693.369	7397648.424	236.401	236.400	0.001	SG
359959	265693.097	7397646.968	236.444	236.440	0.004	SG
359960	265692.883	7397645.956	236.474	236.468	0.006	SG
359961	265692.590	7397644.451	236.519	236.515	0.004	SG
359962	265692.198	7397642.506	236.581	236.569	0.012	SG
359963	265687.275	7397643.516	236.647	236.641	0.006	SG
359964	265687.646	7397645.455	236.581	236.577	0.004	SG
359965	265687.934	7397646.952	236.540	236.537	0.003	SG
359966	265688.457	7397649.402	236.466	236.457	0.009	SG
359967	265688.841	7397651.383	236.403	236.395	0.008	SG
359968	265683.987	7397652.284	236.472	236.471	0.001	SG
359969	265683.568	7397650.364	236.537	236.538	-0.001	SG
359970	265683.211	7397648.933	236.584	236.576	0.008	SG
359971	265683.076	7397647.888	236.615	236.607	0.008	SG
359972	265682.795	7397646.414	236.653	236.650	0.003	SG
359973	265682.387	7397644.473	236.724	236.714	0.010	SG

Average height difference is 0.0039
RMS (Root Mean Squared)   is 0.0053
Mean is 0.0039 with Standard Deviation of 0.0036
0.000% above High tolerance of 20 mm
100.000% within tolerance
0.000% below Low tolerance of 20 mm
End of Report

Field Test 2 Setup Location

Instrument Connection	Instrument Type	Trimble SPS930 1/1
	Serial Number	72611664
	Hz Angle Accuracy	1"
	Vt Angle Accuracy	1"
	DR Single EDM Accuracy	3 mm + 2 ppm
	DR Tracking EDM Accuracy	4 mm + 2 ppm
	IR Single EDM Accuracy	3 mm + 2 ppm
	IR Tracking EDM Accuracy	4 mm + 2 ppm
Instrument Setup	Date	26/07/13
	Time	3:21:29 PM
	Instrument Point Name	---
	Northing	7397624.269 m
	Easting	265705.835 m
	Elevation	237.512 m
	Reference Point Name	59000R
	Northing	7397661.045 m
	Easting	265851.443 m
	Elevation	236.935 m
	Instrument Vertical Height	0.000 m

Plot showing TIN vs Surveyed Points