University of Southern Queensland

Faculty of Engineering and Surveying

EFFECT OF TIME INTERVAL VARIATIONS ON RTK DERIVED DISTANCES

A dissertation submitted by

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ABSTRACT

The research problem statement was to determine if the time elapsed between observing the first and second point when using Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) affected the accuracy and precision of a derived distance between the two points. In particular, this paper focussed on the Queensland cadastral system and RTK derived distances which are to be used on cadastral survey plans. Several days of RTK GNSS (GPS and GLONASS only) data was collected under laboratory type conditions. Several processing strategies and mathematical models were developed to work in conjunction with the zero-distance baseline method to determine distances and produce the results.

The results revealed the one minute data for the latitude distance error at 95% C.I. achieved ± 4.6mm at the 3 minute window and gradually decreased to ± 7.2mm at the 720 minute window and the longitude distance error achieved ± 4.7mm to ± 8.8mm respectively. The five second data ranged from ± 6.9mm to ± 8.6mm for latitude at the 95% C.I. from the 3 minute window to the 720 minute window and the longitude achieved ± 6.4mm to ± 9.0mm respectively.

The five second and one minute data results revealed that there are improvements to accuracy if points can be observed in quick succession. Waiting a pre-determined time between observing the same two points does not improve the accuracy of a derived distance when using a single-base RTK system and the GPS and GLONASS constellations.

In conclusion, the results achieved in this paper is the first step in determining what effects time has on RTK results that the practitioner would realise in their real-life field environment. This first step is vital in not only understanding, the time component of RTK at the field level but to aid in ensuring all economic benefits are realised in an ever-demanding environment and to provide the practitioner with necessary confidence to know the survey being undertaken complies with the survey standards. Further research using different satellite constellations is required for the profession to realise some economic benefit. If the practitioner can re-observe the same point while still located close then there are travel time savings, especially, in rural surveys.

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CERTIFICATION

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

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

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…………………………..
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(Date)

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TABLE OF CONTENTS

ABSTRACT **2**

DISCLAIMER **4**

CERTIFICATION **5**

ACKNOWLEDGEMENTS **6**

TABLE OF CONTENTS **7**

TABLE OF FIGURES **10**

LIST OF TABLES **13**

NOMENCLATURE AND ACRONYMS **14**

CHAPTER ONE - INTRODUCTION **15**

1.1 Problem Statement 21
1.1.1 RTK Accuracy and Precision 23
1.1.2 Point Positioning 25
1.1.3 Precise Point Positioning 26
1.1.4 Temporal and Spatial Error Sources 27
1.1.5 Sky view, Obstructions and their Effects 28
1.1.6 Queensland Survey Standards 30
1.1.7 The Problem 31
1.2 Research Aim 32
1.3 Justification 32
1.3.1 Motivation 34
1.4 Research Method 35
1.4.1 The Solution 35
1.5 Scope and Limitations of the Research Project 36
1.6 Summary 37

CHAPTER 2 – LITERATURE REVIEW **38**

2.1 Introduction. 38
2.2 RTK GPS/GNSS 39
2.3 Queensland Survey Standards and Guidelines 41
2.4 Calibration of GPS/GNSS 44
2.5 Zero-Baselines and Zero-Distance Baselines 46
2.5.1 Previous Zero-baseline Method Research 46
2.5.2 Zero Baseline 48
2.5.3 Zero-Distance Baseline 50
2.6 Averaging and Time Interval (Variations) Windows 54
2.6.1 Averaging 56
2.6.2 Windowing 57
2.5 Conclusions 60

CHAPTER 3 .... **62**

METHODOLOGY 62
3.1 Introduction 62
3.2 Site Selection 63
3.3 Base Station, RTK GNSS Receiver and Radio details 64
3.3.1 Testing Site 65
3.3.2 Base Receiver Information Details: 65
3.3.3 Trimble RTK GNSS Receiver Details: 66
3.4 Site Specifics 68
3.4.1 Equipment Validation 71
3.4.2 Ancillary Equipment 72
3.5 Using Zero-distance Baseline Testing Method 73
3.6 Data Collection Verification Process 73
3.6.1 National Marine Electronics Association 74

3.6.2 Data Evaluation/Integrity....76
3.6.3 Data Processing....76
3.6.4 Processing Strategy....77
3.6.4.1 Single Epoch Processing Strategy....77
3.6.5.2 Five Second Averaged Single Epochs of Collected Data....78
3.6.5.3 One Minute Averaged Single Epochs of Collected Data....78
3.6.5.4 Tiers of Processing Strategy....79
3.6.6 Validation Method of Computations....81
3.7 Conclusion of Chapter 3....84

CHAPTER 4....86

4.1 Introduction....86
4.1.1 Data Validation....87
4.1.2 Single Epoch Data Analysis....93
4.1.3 Single Latitude Epochs Defined....97
4.1.4 Single Longitude Epoch Defined....99
4.1.5 Notes....100
4.2 Five Second/Three Minute Window Dataset at 95% Confidence Interval....100
4.3 Five Second Observation Time with Increasing Windows at 95% Confidence Interval....105
4.4 Five Second Observation Time at the Thirty Minute Window....108
4.5 Five Second/Ninety-fifth Percentiles....111
4.5.1 Five Second/Ninety-fifth (95th) Percentile Distances....111
4.5.2 Region at which 95th Percentile of Five Second Data Falls....112
4.6 One Minute Observation Time Dataset....113
4.6.1 One Minute – with Thirty Minute Window Point Positions at 95% C.I.....114
4.6.2 One Minute Dataset – Maximum and the 95th Percentile Distances....115
4.6.3 Region at which the Ninety-fifth Percentile of One Minute Data Falls....117
4.7 One Minute Observation Time with Increasing Windows at 95% Confidence Interval....118
4.8 Five Second and One Minute Observation over Increasing Windows at 95% Confidence Interval....120
4.9 Summary....121

CHAPTER 5....122

RESULTS and DISCUSSION....122
5.1 Introduction....122
5.2 Discussion....122
5.3 Results....124
5.3.1 Single Epoch Data Analysis....124
5.3.2 Single Latitude Epochs Defined....124
5.3.3 Single Longitude Epochs Defined....124
5.3.4 Five Second/Three Minute Window Point Positions at 95% Confidence Interval....125
5.3.5 Five Second Observation Time with Increasing Windows at the 95% Confidence Intervals....126
5.3.6 Five Second Observation Time at the Thirty Minute Window....127
5.3.7 Five Second/95th Percentiles....128
5.4 One Minute Observation Time Dataset....128
5.4.1 One Minute Dataset Point Positions with increasing Windows at the 95% Confidence Interval....128
5.4.2 One Minute – with Thirty Minute Window Point Positions at 95% C.I.....129
5.4.3 One Minute Dataset – Maximum and the 95th Percentile Distances....130
5.4.4 One Minute Observation Time with Increasing Windows at 95% Confidence Interval....134
5.5 Five Second and One Minute Observations over increasing Windows at the 95% Confidence Interval....135
5.6 Summary....136
5.7 Implications....137

CHAPTER 6....138

CONCLUSION....138
6.1 Introduction....138
6.2 Meeting the Aims and Objectives....138
6.3 Findings and Recommendations....139
6.4 Compliance to Standards....139
6.5 Observation Times....140
6.6 Time Windows....140
6.7 Further Research....141

6.8 Recommendations 144
6.9 Conclusion and Project Closure 145
REFERENCES 146

APPENDIX A – PROJECT SPECIFICATIONS 150

TABLE OF FIGURES

FIGURE 1: RADIAL SURVEY TECHNIQUE 23

FIGURE 2: RTK OBSERVATION TECHNIQUE 24

FIGURE 3: ERRORS 28

FIGURE 4: SIGNAL OBSCURATION 29

FIGURE 5: RTK DERIVED DISTANCE 31

FIGURE 6: RTK RADIAL SURVEY 34

FIGURE 7: SPLITTER FOR ZERO-BASELINE SETUP 48

FIGURE 8: SPLITTER AND GEODETIC ANTENNA SETUP 49

FIGURE 9: SIMULTANEOUS TRIGGERING OF BOTH VRS & RTK 49

FIGURE 10: USQ TRIMBLE ZEPHYR MODEL 2 ANTENNAE 50

FIGURE 11: ZERO-DISTANCE ERROR WITH BEARING ERROR INCLUDED 51

FIGURE 12: TRUE ZERO-DISTANCE BASELINE 52

FIGURE 13: AVERAGING FIGURE 14: WINDOWING 57

FIGURE 15: ACCURACY DEFINITIONS 59

FIGURE 16: RINGS OF ACCURACY FOR GPS 59

FIGURE 17: POSITION ACCURACY MEASURES 59

FIGURE 18: USQ CORS BASE STATION 'ANANGA' 63

FIGURE 19: 'ANANGA' CORS PSM 64

FIGURE 20: SKY VIEW & STAY WIRES 65

FIGURE 21: LIGHTNING RODS 66

FIGURE 22: TRIMBLE R8-3 RTK GNSS RECEIVER 67

FIGURE 23: USQ RTK GNSS GEODETIC ANTENNA 67

FIGURE 24: GPS SIGNAL SPLITTER 68

Figure 25: Re-broadcaster USQ Z-Block Z120 69
Figure 26: Antenna Phase Centre 70
Figure 27: Trimble Zephyr Geodetic Model 2 Antenna 71
Figure 28: Antenna Measurement 71
Figure 29: USQ 450 TDL Radio 72
Figure 30: NMEA-0183, GGA Field Code 75
Figure 31: 90 Degrees/1.0m Inverse Solution 82
Figure 32: 90 Degrees/1.0m Direct Solution 82
Figure 33: 90 Degrees/1.0m Excel Longitude Check 82
Figure 34: Zero Degrees/1.0m Direct Solution 83
Figure 35: Zero Degrees/1.0m Inverse Solution 83
Figure 36: Excel Formulae Latitude Check 83
Figure 37: 6km to 22km at 68% 88
Figure 38: 15km to 41km at 68% 90
Figure 39: 50km to 70 at 68% 91
Figure 40: Latitude Point Position Range with 95% C.I. of dataset included. 96
Figure 41: Longitude Point Position Range with 95% C.I. of the dataset 97
Figure 42: Single Epoch Latitude Point Position Histogram 97
Figure 43: Single Epoch Latitude Point Position Descriptive Statistics 98
Figure 44: Single Epoch Longitude Point Position Histogram 99
Figure 45: Single Epoch Longitude Point Position Descriptive Statistics 99
Figure 46: Windowing Effect 101
Figure 47: 5 Second/3 Minute Longitude Distance Errors with 95% C.I. 102
Figure 48: 5 Second/3 Minute Latitude Distance Errors with 95% C.I. 103
Figure 49: Latitude Distances Histogram 103

Figure 50 : 5 Second/3 Minute Longitude Distance Histogram 104
Figure 51: Pictorial of the 5 second averaged epoch precisions over increasing time windows at 95% C.I. 105
Figure 52: Re-graphed 5 Second dataset over increasing windows at 95% C.I. 106
Figure 53: 5 Second/30 Minute Window Distribution Histogram...................................108
Figure 54: Longitude - 5 Second/30 Minute Window Distribution Histogram 108
Figure 55: Latitude 5 Second/30 Minute Window Distances 109
Figure 56: Longitude 5 Second/30 Minute Window Distances..109
Figure 57: 95th Percentile - Absolute Measured Distance at Increasing Windows...........111
Figure 58: 95th Percentiles – the value at which 95% of data falls below 112
Figure 59: Re-graphed Figure 58 - 3 Minute to 90 Minute Windows...............................112
Figure 60: 1 Minute Dataset Point Positions at increasing Windows at 95% C.I. 113
Figure 61: 1 Minute/30 Minute Window Latitude and Longitude Point Positions with the 95% Confidence Intervals..115
Figure 62: 95th Percentiles - Distances and Maximum Distances 116
Figure 63: 1 Minute/95th Percentile Latitude & Longitude - 3m to 720m Windows 117
Figure 64: 1 Minute Dataset - Precision at 95% C.I. as a Function of Time 118
Figure 65: Distance Error as a Function of Time...128
Figure 66: 1 minute/30 minute Point Positions 130
Figure 67: 1 Minute 95th Percentile Distances overlaid with the 95% C.I. 131
Figure 68: 1 Minute - 95th Percentile & Maximum Distances with the 95% C.I. 132
Figure 69: NRTK vs RTK: DISTANCE Deviations from the Mean 133
Figure 70: 1 Minute/Increasing Windows - Latitude and Longitude 95% C.I. Distance Error overlain with CSR Vector Accuracy 134
Figure 71: 1 Minute & 5 Second Datasets at increasing windows at 95% C.I....................135

LIST OF TABLES

TABLE 1: 95% CONFIDENCE INTERVAL OF 201848 SINGLE EPOCHS OF COLLECTED DATA....................92

TABLE 2: RANGE OF SINGLE EPOCH LATITUDE AND LONGITUDE POINT POSITIONS.............................94

TABLE 3: LATITUDE AND LONGITUDE SINGLE-EPOCH 95% CONFIDENCE INTERVAL OF THE POINT POSITIONS. 95

TABLE 4: RHO & NU CORRECTED FOR HEIGHT AT THAT POINT..95

TABLE 5: SINGLE EPOCH POINT POSITION COLLECTED DATA MEAN/MEDIAN/MODE DIFFERENCES. 100

TABLE 6: DESCRIPTIVE STATISTICS FOR 5 SECOND/3 MINUTE WINDOW DATASET.............................102

TABLE 7: TABULAR DESCRIPTION OF THE 5 SECOND DATASET OVER INCREASING TIME WINDOWS AT 95% C.I...106

TABLE 8: RANGE OF 5 SECOND DATASET AT INCREASING WINDOWS..107

TABLE 9: 5 SECOND/30 MINUTE WINDOW STATISTICS 110

TABLE 10: 5 SECOND/95TH PERCENTILE AND MAXIMUM DISTANCES 111

TABLE 11: 5 SECOND - 95TH PERCENTILES AT INCREASING WINDOWS 113

TABLE 12: 1 MINUTE DATASET POINT POSITIONS AT INCREASING WINDOWS AT 95% C.I................114

TABLE 13: 1 MINUTE/30 MINUTE LATITUDE AND LONGITUDE POINT POSITIONS WITH THE 95% C.I. 115

TABLE 14: 1 MINUTE DATASET WITH INCREASING WINDOWS - 95TH PERCENTILE DISTANCES...........116

TABLE 15: 1 MINUTE - 95TH PERCENTILE LATITUDE & LONGITUDE - 3M TO 720M WINDOWS.........117

TABLE 16: 1 MINUTE DATASET AT INCREASING WINDOWS AT 95% C.I. 119

TABLE 17: 1 MINUTE & 5 SECOND DATASETS AT INCREASING WINDOWS AT 95% C.I. 120

TABLE 18: 1 MINUTE DATASET AT INCREASING WINDOWS AT 95% C.I. 129

TABLE 19: 1 MINUTE/30 MINUTE POINT POSITIONS...130

TABLE 20: 1 MINUTE & 5 SECOND DATASET AT INCREASING WINDOWS AT 95% C.I.......................136

NOMENCLATURE AND ACRONYMS

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

APC	Antenna Phase Centre
CI	Confidence Interval
CQ	Coordinate Quality
CORS	Continuously Operating Reference Station
CSR	Cadastral Survey requirements
DOP	Dilution of Precision
DoD	Department of Defence in America
EDM	Electronic Distance Measurement
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICSM	Intergovernmental Committee on Surveying and Mapping
MGA	Map Grid of Australia
PPP	Precise Point Positioning
ppm	parts per million
PSM	Permanent Survey Mark
RTK	Real-time Kinematic
SBQ	Surveyors Board of Queensland
SIS	Signal-in-Space
SMI Act	Surveying and Mapping Infrastructure Act 2003
SPS	Standard Positioning Service
SP1	Special Publication #1
SV	Space Vehicle
USQ	University of Southern Queensland.

CHAPTER ONE - INTRODUCTION

There are several grades of Global Navigation Satellite Systems (GNSS) instruments and systems available to suit all needs. The systems are defined by their positional accuracy capabilities. The can be further defined as civilian, mapping, surveying and military grade. The most basic GNSS point positioning system is used for recreational purposes such as orienteering, fishing, boating and the in-car navigation system. The quality of information coming out of a GNSS is dependent on the quality of the information going in and the quality of the information has a cost associated to it. The more accurate and precise the more expensive. Real-Time Kinematic (RTK) is a survey grade technique which utilises the signal from GNSS to obtain a point position in real time.

RTK, like all surveying systems, does have accuracy and precision limitations which are caused by systematic errors that occur prior to the receiver accepting the broadcast navigation signal. RTK's introduction into Australia prompted regulatory agencies to update the existing survey standards and guidelines. These standards and guidelines have been dynamic, based on substantiated quality research and reflect the technological changes and developments as they occurred or became apparent. These accomplishments have prompted the requirement for more research. Recent times has seen more research on the temporal characteristics of using the RTK technique to derive distances between separate observations.

These derived distances are used for many applications such as; pegging land allotments and displaying ground distances on survey plans, engineering setout works and civil construction operations to list a few. Therefore, accurate determination of these distances is paramount. In some instances, considerable time can elapse before a practitioner can observe the second point which is needed to derive (compute) a distance between two points. This time interval could be as short as three or four minutes or as long as hours and even days at times. The effect of time interval variation when using RTK to derive a distance demands further research to assess if any changes occur to the normal RTK error budget.

With due regard to other applications and professions, the importance of an accurate cadastre and State Database is also paramount when considering the importance of land to the economy. The intent of this dissertation is to develop a workable mathematical model to extrapolate distances from the collected data and determine the maximum, minimum, range, standard deviation and ninety-five percent (95%) confidence interval of pre-determined averaged datasets and increasing time interval windows. As appropriately mentioned in the previous sentence this research project is about derived distances between points at either end of a line when using an RTK single-base system.

Put into a simple context, the zero-distance baseline accepts that the RTK observations are random and the distances are calculated between the observations as they 'wander' around. To elaborate, if we observe a position now, we achieve a set of coordinates (say -26° 30' 00", 150° 30' 00") computed by the data recorder setup parameters e.g. average of 5 epochs. We wait 30 minutes and re-observe the same point and achieve coordinates of say, -26° 30' 30" & 150° 30' 30". The difference between these two coordinates is the zero-distance baseline (a distance expressed in metres in a one dimensional form – latitude and longitude) and, obviously, because of the temporal and spatial errors associated with RTK the coordinates of the same point 'wander' around within the normal RTK error budget. This research project accepts the normal RTK error budget and concentrates more on how the practitioner can work with it. No one observation is accepted as the true value for a point. It does not compute a mean of the sample.

Initially, to set a benchmark, the single epochs of latitude and longitude will be statistically analysed and graphed to ascertain trends, behaviours and patterns. Following, the mathematical model will derive the arithmetic mean of the 201848 single epochs of collected data. Next, the entire dataset will be divided into the predetermined sets of averaged epochs of data of five second and one minute sets. These averaged epochs of data will be called datasets and will represent observation time on the point and are designed to replicate how long the practitioner might feasibly spend observing a point. The five second average was chosen to set a platform which is well below any recommended time span by notable researchers (Edwards et al. 2010; Gibbings & Zahl 2014a; Janssen & Haasdyk 2011b) and below the minimum recommended time in the latest Queensland Cadastral Survey Requirements (Spatial Policy of Department of Natural Resources and Mines. *Cadastral Survey Requirements* 2015, Version 7.0). The one minute observation was chosen to allow for comparisons with the single epochs of latitude and longitude, the five second platform and a combination of all when appropriate.

The time interval variation, from this point forward called a time interval window or simply a window, sampling rate will commence at three minutes. The rate will then be increased to five (5) minutes (m), 10m, 15m, 20m, 25m, 30m, 60m, 120m, 240m, and when/if required extended to include 360m, 600m and cease at 720m (12 hours).

The time interval of 720m or twelve hours is to ensure the twelve hour orbit cycle of the Space Vehicles (SV) is accounted for and the many multiple variations of satellite configurations are experienced. Next, whilst holding the first window of five (5) seconds the maximum, minimum, range, standard deviation and the ninety-five percent (95%) confidence interval (C.I.) will be calculated for the entire time interval sampling windows/increments. The 5 second dataset will undergo a single analysis and subsequent graphing, involving increasing the time window to ascertain what effect time windows has on precision.

The 5 second and 1 minute datasets will be analysed and graphed together at increasing time windows and compared with the single epoch analysis and against one another as appropriate. This mathematical process will be rigorous for all windows and the results graphed against an absolute zero-distance baseline. The zero-distance baseline produces distances relative to the true value coordinates and are expressed in metres. All residual distance errors will be expressed in metres as latitude and longitude separately and respectively and graphed accordingly.

Every instrument has intrinsic uncertainty when measuring the same point multiple times and this uncertainty is usually stated as a constant and a distance dependent parts per million (ppm) error. The RTK error is expressed in this same manner but its accuracy and precision has a pattern and at the same time a randomness that is caused by several temporal errors. The ever-changing satellite configuration, timing errors and the lack of a yet-to-be discovered suitable model that addresses the atmospheric and tropospheric conditions that broadcast ephemeris must travel through are some of the factors that contribute to the error budget of RTK.

These errors, which are uncontrollable by human intervention, change as time expires and the multitude of factors that affect these errors are inconsistent in themselves. The significance of this phenomenon must be understood so the mathematical model is designed to extract the necessary statistical data to be evaluated. Each epoch of data is a random variable in itself and each windowed dataset will be a random variable in itself also.

Each satellite has its own inherent errors and to overcome this the software inside the receiver has a specifically designed set of satellite selection algorithms. These algorithms allows the software to select a number of the most suitable satellites which have the lowest Dilution of Precision (DOP) values (Langley 1999). DOP is, basically, a measure of the number of visible satellites and their three dimensional position. The lower the DOP the better the estimate of the position to its true value. The minimum number of satellites required to obtain a resolution is four. One to solve for each of the four unknowns; x, y, z and time.

It is common to measure the quality of the results by determining the mean but precision determines the repeatability. As the dataset is windowed it is expected that random variability will become somewhat hidden or disguised and it is also envisaged the range established by averaging the entire dataset will remain constant. On derivation of the results from the mathematical model comparisons will be made to the current Queensland survey standards.

In Queensland, the Department of Natural Resources and Mines (DNRM) and the Surveyors Board of Queensland (SBQ) are the primary regulatory authorities. Global Satellite System (GPS) were introduced into Australia in 1994 and the main surveying manuals for surveyors was the Surveyors Operational Manual (SOM) and the Board Operational Manual (BOM). Like any new technologies 'teething problems' can be experienced and as time expired RTK presented its own challenges.

Some of these challenges presented themselves in late 2012, when the Surveyors Board of Queensland recognised there were some issues and potential confusion amongst practitioners regarding the use of RTK for cadastral surveying. This prompted the SBQ to release a guideline (Surveyors Board of Queensland November, 2012) which provided clarification on the identified issues. Since then Gibbings, P. & Zahl, M. (2014b) have released two articles with the express intention of emphasising the specific capabilities and limitations of RTK. Gibbings, P. & Zahl, M. (2014b) made comparisons between the results of their testing and the current Queensland cadastral surveying legislation, survey standards and recommended guidelines.

The Surveying and Mapping Infrastructure Act 2003 (SMI Act) and the Surveyors Act 2003 provides legislative support to the Department of Natural Resources and Mines (DNRM) and the SBQ. The Cadastral Survey Standards (CSR) is a standard under of the Surveying and Mapping Infrastructure Act 1994 (SMI Act) and Section 3.4.2 (Measurement Accuracy) of the CSR (commonly known as Survey Standards) provides several determinations as to how the accuracy of a cadastral survey in terms of both angular and linear misclose can be achieved. DNRM has recently released version 7.0 of the cadastral survey requirements.

Version 7.0 of the CSR includes an entire chapter on the use of Global Navigation Satellite Systems (GNSS) for cadastral surveying in Queensland. This new version does provide much needed clarification on the issues identified by the SBQ but it is not completely exhaustive. Previous research by Gibbings and Zahl (2014) has already provided sufficient support for these new changes but it, also produced more questions and the need for more research to further advance the understanding of RTK.

Therefore, it is a prerequisite and a professional obligation on spatial science students and professionals to continue expanding on the existing research. This is especially correct given the new SBQ guideline (2012), the release of the new CSR's and the increased pressure on practitioners to comply with relevant standards.

1.1 Problem Statement

Does the time elapsed between observing the first point and second point when using RTK GNSS, affect the accuracy and precision of the derived distance between the two points? This elapsed time will be referred to the 'time interval variation or time interval window or window' from this point forward. No measuring instrument can measure a distance perfectly and RTK GNSS is no exception. This imperfection is often referred to as an error budget or biases'. The error budget consists of random, systematic and gross errors. It is well-known and proven that the errors that influence the final RTK positions have the potential to create survey standard compliance issues for the survey profession, especially, when the survey standards appear more stringent than the known limitations and capabilities of an RTK system (Gibbings & Zahl 2014b; Higgins 2001). However, there has been little research on what effects time interval variations has on RTK derived distances. That is, does the time elapsed between observing the first point and the second point affect the accuracy and precision of a derived distance?

Conventional surveying instruments, sometimes referred to as Terrestrial Instruments (TI), Electromagnetic Distance Measurement Equipment (EDME) or a Total Station (TS), are not affected by the errors associated with RTK. However, TI's, TS's and EDME's can be affected by other more localised issues such as the local climatic conditions. The local meteorological data is entered into them and the survey commences and is, generally, completed within the manufacturers' instrument specifications provided the obligatory check and balances are in place. TI's, if standardised correctly, are capable of consistently measuring the same distance to the same level of accuracy and precision between the same two points, as per the individual instrument manufacturer's specifications, day after day. The same level of accuracy and precision mentioned in this context satisfies the current Queensland survey standards. RTK does not have this ability.

In fact, RTK surveys are radial in nature and distances between two points being observed is calculated and not measured. In addition to this, due to its inherent errors, it is extremely difficult for RTK to achieve or repeat the same computed distance or level of accuracy and precision between the same two observed points after multiple attempts. However, RTK's main advantages are its ability to measure longer distances which negates the need for multiple setups and it is not subject to intervisibility issues like conventional TI's.

1.1.1 RTK Accuracy and Precision

Many researchers have, since the inception of GPS, established the accuracy and precision for point positioning using RTK and the subsequent effects to a distance on a calculated line (Gibbings & Zahl 2014b). 'Calculated or derived' meaning not measured because RTK surveys are radial in nature. However, to the authors' knowledge, little research exists which describes what the effects are to an RTK derived distance as the time between observing the first and second point increases. As seen in Figure 1, the RTK surveying technique is similar to undertaking a topographic survey with a conventional survey instrument.

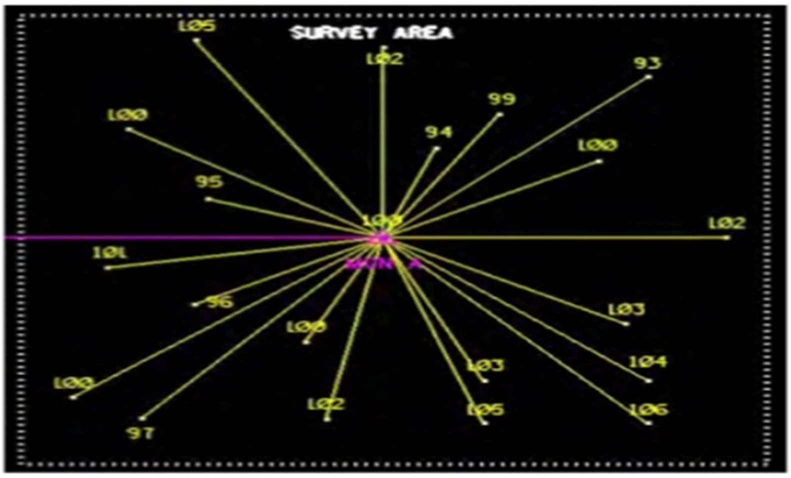


Figure 1: Radial Survey Technique
Source: http://www.slideshare.net/xuhui6996/em-1110-11005-control-and-topographic-surveying.

An RTK receiver uses the carrier phase and code observables to define its position and the accuracy and precision of its point is estimated because orbital errors, satellite clock errors, multipath and atmospheric errors (Olynik 2002) are predicted. These errors can be well managed and to some extent reduced by adopting suitable techniques (Higgins 2001; Spatial Policy of Department of Natural Resources and Mines 2010-Version 6.0, Reprint 2.; Surveyors Board of Queensland 2012)

The correct management of these errors can improve the positional and local uncertainty (Inter-Governmental Committee on Surveying and Mapping (ICSM) October 2014) of its point.

RTK is a passive system unlike conventional surveying instruments which receive a return signal. This gives the conventional instrument an advantage because it sends and receives multiple signals, as defined by the operator, which in itself has some 'redundancy' effect. An RTK system receives a data signal continuously, as seen in Figure 2, and this signal contains errors outside the control of the user. Attached to this signal is the broadcast ephemeris. The broadcast ephemeris contains predications on where the satellite (spatial position), commonly called a space vehicle (SV), should be and not where it truly is. This is defined as orbital errors and each SV has its own prediction errors. It is not until the SV has passed a point before its true spatial position can be accurately determined and, therefore, defining the rover receiver's more accurately. The main advantage of RTK would be lost if post processing of data is required.

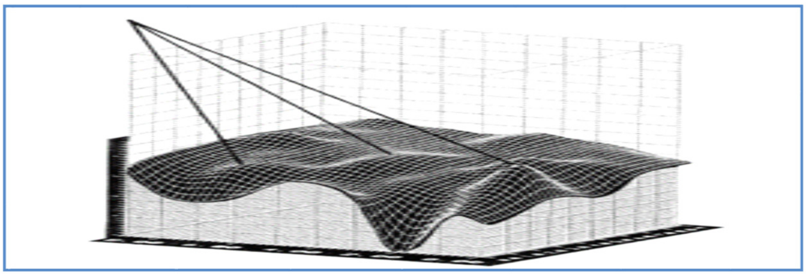


Figure 2: RTK Observation Technique
Source: Langley, RB 1991, 'The orbits of GPS satellites', *GPS World*, vol. 2, no. 3, pp. 50-3.

The instrument collecting the data, commonly called a data collector, has built in mathematical statistical algorithm's which, based on the parameters and definitions set by the user, accepts a predetermined number of epochs of data and mathematically obtains the most probable value (MPV) for the point position. While this process appears to isolate and neglect the errors previously mentioned it only reduces the likelihood of accepting outliers by the use of simple statistics.

Outliers still exist and, initially, the user must rely on confidence, baseline accuracies and Root Mean Square (RMS) values (highlighted on the status line on the data recorder) before accepting the coordinates of the point. Whilst the magnitude or randomness of these errors are not immediately noticeable there are appropriate survey techniques available which are used to reveal them.

1.1.2 Point Positioning

Most new vehicles today come equipped with an in-car navigation system and a recreational handheld GPS can be purchased for a few hundred dollars. There is no special GPS receiver signals associated with the different grades of GPS instead the internal software of individual grade GPS receivers have different capabilities for extracting relevant information from the signals to achieve certain levels of accuracy and precision. Obviously, purchase prices vary accordingly.

In short, recreational and professional GPS units are designed and built for different purposes. As a general rule, recreational GPS's have a positional accuracy of ±10m, whereas survey grade RTK systems has a positional accuracy of less than ±0.1m.

1.1.3 Precise Point Positioning

In the 1990's, the Jet Propulsion Laboratory at the National Aeronautical Space Agency (NASA) in America pioneered new techniques that did not require differencing to obtain precise positions. They labelled it Precise Point Positioning (PPP) (Nistor. S & A.S. 2012). The word 'Precise' is used in the description to differentiate it from relative point positioning. PPP is different from RTK. RTK requires two receivers, one base receiver and one rover receiver whereas PPP requires a rover receiver only. PPP receives differential corrections via kinematic or static mode and relies on predicted satellite orbits, ionospheric models and real time satellite estimates (van Bree & Tiberius 2012) to establish its position. Basically, PPP's point position uses a GNSS code observable and the navigation message. The accuracy and precision of PPP is generally greater than RTK (van Bree & Tiberius 2012).

Research and testing by van Bree & Tiberius (2012) achieved standard deviations of 0.15 and 0.30m for the horizontal and vertical coordinates, respectively, with 95% error values of approximately 0.30m and 0.65m. PPP is available through commercial service providers for a fee and only a single GNSS receiver is needed which suggests the cost of the fee is offset by the lack for the need for a base receiver.

PPP has lower positional accuracy than RTK which makes it unsuitable for cadastral surveying in Queensland. PPP also requires longer convergence times, is not constrained by baseline length and presents an efficient alternative for applications such as navigation, exploration, agriculture and fire and rescue services.

1.1.4 Temporal and Spatial Error Sources

The American Department of Defence (DoD) established the conventional GPS system for military purposes and maintains full control and authority with the system. The following passage taken from Section 2.4.5 (Excluded Errors) of the '*Global positioning system standard positioning service performance standard*' (DoD 2001) page 15, provides clear and definitive evidence of the errors associated with GNSS systems (refer Figure 4). Note dot points with the following superscripts 1, 2, 3, 4, 6 and 7 are not controllable by any human source and can occur randomly but are always present and have a direct influence on the final position (refer to Figure 3).

"The performance standards in Section 3 of this SPS PS do not take into consideration any ***error source that is not under direct control of the Space Segment or Control Segment***. Specifically excluded errors include those due to the effects of:

- Signal distortions caused by ionospheric and/or tropospheric scintillation[1]
- Residual receiver ionospheric delay compensation errors[2]
- Residual receiver tropospheric delay compensation errors[3]
- Receiver noise (including received signal power and interference power) and resolution[4]
- Receiver hardware/software faults[5]
- Multipath and receiver multipath mitigation[6]
- User antenna effects[7]
- Operator (user) error[8]."

A substantial amount of research has established the spatially and temporally correlated errors (El-Rabbany & Kleusberg 2003; Olynik 2002) which affects the accuracy and precision of RTK. Spatially correlated errors occur when the magnitude of the error is similar at two different locations and errors are temporally correlated when their magnitude is similar over a period of time (Miller, O'Keefe & Gao 2012).

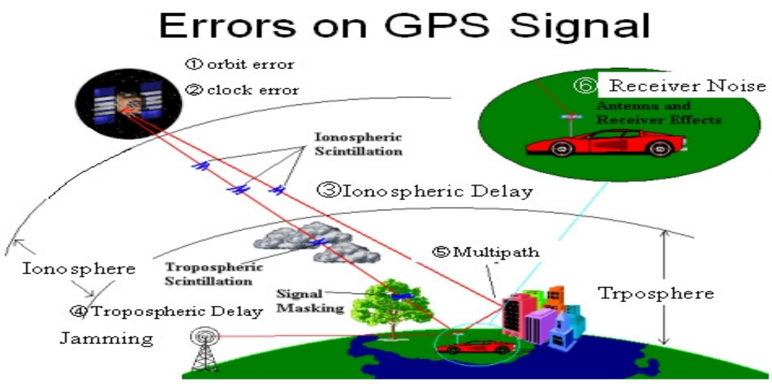


Figure 3: Errors
Source: http://forum.xda-developers.com/showthread.php?t=1697306.

1.1.5 Sky view, Obstructions and their Effects

Dilution of Precision (DOP), in GPS positioning, is an indication of the geometric strength of the configuration of the satellites in a particular constellation at a particular moment and hence the quality of the results that can be expected (Van Sickle 2011). The following statement taken from Section B.4.3 of the '*Global positioning system standard positioning service performance standard*' (DoD 2001) page B38 and the following supporting figure 1, provide an explanation on how the Dilution of Precision (DOP) values can alter when lock is lost on one satellite only.

Even when there is only one nearby obstruction that only blocks one SPS (Standard Positioning Service) SIS (Signal-In-Space), the loss of that SPS SIS can radically alter the DOP values. In such obstacle-rich environments, it is difficult to try to predict in advance which satellite's SPS SIS will be blocked and when that blockage will start or end (DoD 2001).

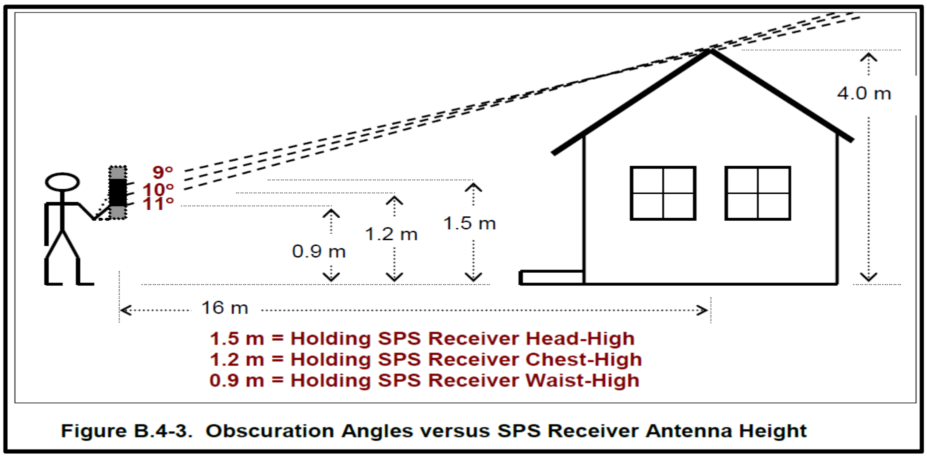


Figure 4: Signal Obscuration

Sourced: http://www.navcen.uscg.gov/pdf/gps/geninfo/2001SPSPerformanceStandardFINAL.pdf

The above-mentioned comment and Figure 4 relates specifically to the use of RTK in an American urban environment. However, the paradigm is applicable to all world locations and environment. A close inspection of Figure 4 reveals the minimum elevation mask is 9° which is not a recommended standard under the current Queensland Cadastral Survey Requirements. Figure 4 does highlight the effect obscuration can have on RTK results especially if it being used where obstructions do exist.

1.1.6 Queensland Survey Standards

Section 3.4.2 (Measurement Accuracy) of the Cadastral Survey Requirements (CSR), Version 7.0, states the accuracy of a cadastral survey in terms of both angular and linear misclose, and then goes on to add the requirement that, '*All surveyed lines (e.g. boundary lines, connections) must have a vector accuracy of 10 millimetres + 50 ppm*' (Spatial Policy of Department of Natural Resources and Mines. *Cadastral Survey Requirements* 2015, Version 7.0). Therefore, accurate determination of the distances involved is paramount if compliance is to be achieved regardless of whether the survey is undertaken using a geodetic or conventional terrestrial instrument. The CSR must be read and interpreted in conjunction with the SMI Act, the Surveyors Act and Special Publication 1 (SP1), Version 2.1 (Inter-Governmental Committee on Surveying and Mapping (ICSM) October 2014).

SP1 is a guideline developed by the Intergovernmental Committee on Surveying and Mapping (ICSM) which is part of the Permanent Committee on Geodesy (PCG). The guidelines' primary purpose is to promote the adoption of uniform Global Navigation Satellite System (GNSS) surveying procedures to achieve the highest level of rigour and integrity in Australia's survey control mark network (Inter-Governmental Committee on Surveying and Mapping (ICSM) October 2014). The guideline outlines ICSM's recommended equipment and procedures for GNSS surveying in Australia.

1.1.7 The Problem

The SBQ guideline and Gibbings, P. & Zahl, M (2014b) articles have answered some of the questions regarding the use of RTK for cadastral surveying in Queensland. While the above articles have advanced the practitioners understanding they have produced the need for more research with regard to RTK and time interval variations/window. To the author’s knowledge, there appears to be a distinct lack of research with regard to time interval variation/window when using RTK.

The time interval window can be defined as;

1. The length of time that elapses between observing the first point and the second point from which the derived RTK distance is to be calculated (refer Figure 5).

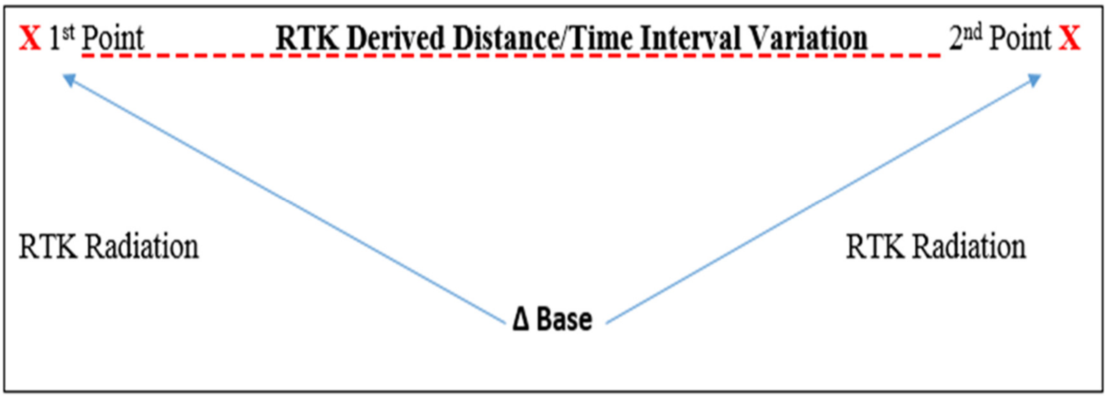


Figure 5: RTK Derived Distance

This time interval window and an apparent lack of research produces the following question;

What are the effects to the calculated distances between two points if the practitioner does not get to measure a reference point at the opposite end of a line, for which a distance must be derived, for several hours or until the following day or days?

This question has many hidden factors and disassembling into relevance produces;

- Are there any effects to an RTK derived distance as the time between observing the first and second end point increases and the satellite constellation configuration changes?
- Will the well-known existing RTK error budget be affected in any way (accuracy, precision, range, standard deviation and confidence limit)?
- Will the outcome have any effect on the existing proven RTK survey technique (Surveyors Board of Queensland November, 2012) (Higgins 2001) (Gibbings & Zahl 2014b) (Spatial Policy of Department of Natural Resources and Mines. *Cadastral Survey Requirements* 2015, Version 7.0)?
- And will the outcome affect the practitioner or their practices in terms of compliance?

1.2 Research Aim

The aim of this research is to investigate the effect of time interval variations (windows) on a derived distance when using RTK.

1.3 Justification

The new Queensland Cadastral Survey Standards have a section dedicated to the use of GNSS for cadastral surveying. In 2012, the SBQ identified some issues existed regarding the use of RTK for cadastral surveying and determine that clarification was required to help practitioners to understand and use this technology in the appropriate manner. Specifically, there seemed to be potential confusion over the limitations of RTK GNSS, namely, the accuracies and precisions of derived dimensions (Gibbings & Zahl 2014a).

In 2014, Gibbings and Zahl (2014b) released two articles which are essential, as well as an adjunct to, in advancing the practitioners knowledge and resolving this confusion within the profession.

Previous research has identified a technological gap which relates specifically to time interval variations. This time-based technological gap demands a resolution to ascertain if the existing error budget associated with RTK surveys is altered in any form. This dissertation sets out to derive an outcome with respect to the time interval variation/window and make comparisons between the outcome and the CSR's as the time between observing points at separate ends of a calculated line increases.

This new research will aid in narrowing the technological gap that presently exists in assessing what effects time has on RTK derived distances. Being new research will make it somewhat difficult to make comparable comparisons with previous research. However, there is previous research into mathematical models, Kalman filtering processes (Bisnath & Gao 2009), temporal characteristics (Odijk, Teunissen & Huisman 2012), stochastic modelling and time series analysis of GPS observables (Borre & Tiberius 2000) which relates specifically to the spatial component of the temporal characteristics of RTK.

The recent research by such researchers as Gibbings and Zahl (2014a), Janssen & Haasdyk (2011b) and Edwards et al. (2010) will be referred to often because of the context in which the data was collected, processed and what the results represent in the real-life scenario.

It must be remembered the RTK technique is radial in nature (see Figure 6.) and subject to errors outside of the control of the surveyor. Note, also, in Figure 6 that the distances between stations B – C, C – D, D – E and E – F are not actual measured but computed from RTK coordinate values.

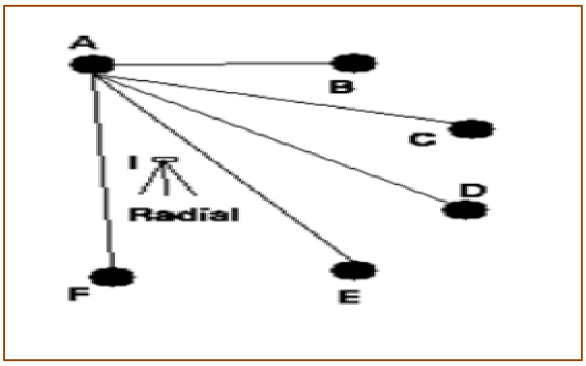


Figure 6: RTK Radial Survey

Sourced: http://www.gisresources.com/wp-content/uploads/2013/08/REM3.png.

1.3.1 Motivation

Since the inception of RTK GNSS it has been comprehensively researched by academia, governments, professional authorities and other geodetic agencies. As a result of this research the advantages, disadvantages, capabilities and limitations of RTK are well established. But not all questions are answered and further research is required.

Apart from this being a mandatory educational requirement for me to successfully obtain my Bachelor Degree in Spatial Science (Hons). I see this opportunity as the first step of many towards my official participation in the geodetic academic world.

1.4 Research Method

1.4.1 The Solution

Answers are required to this problem. An outcome is required to determine if time interval variations/windows has any effect on the expected normalised error budget and if, in terms of compliance, the RTK techniques prescribed in the Queensland survey standards and Special Publications 1 (SP1) are being challenged. To achieve the outcome more research and subsequent testing is essential. Firstly, any mathematical model must have the ability to isolate the time interval window residuals. Secondly, the processing strategy must have the proficiency to isolate any anomalies and errors (in the first instance) and then identify trends, behaviours, randomness and patterns. This will be achieved in the following manner;

- Collect a sufficient amount of RTK data taking the 12 hour satellite orbit configuration and change into account,
- Producing a mathematical model and processing strategy to vary the observation time intervals/windows and gradually increase the time interval window between observing the first and second observation point and determine the residuals using the zero-distance baseline technique,
- Graph the residuals in single dimension, Latitude (Northing) and Longitude (Easting) in metres, with respect to accuracy and precision as a function of time at the ninety-five percent (95%) Confidence Interval (C.I.),
- Make comparisons to the existing CSR, current recommended RTK survey techniques, make recommendations and assess the need for further research.

1.5 Scope and Limitations of the Research Project

This dissertation has defined the problem in Section 1.3.1 and that problem is to derive an outcome regarding the time interval variations/windows associated with RTK and evaluate the outcome. During the testing, the time interval windows will be modified to exhaust all opportunity for any non-compliant configurations and more reliable techniques to be identified and evaluate any subsequent potential effects on RTK surveying.

The limitations of this research is:

- The data was collected using conventional GPS and GLONASS satellite constellations
- There are no setup errors because the antennae are on single poles, dyna-bolted to a concrete floor and held in place by adjustable steel stay wires
- The base station is a permanent CORS station and is also securely held in position
- The research data is multipath free
- The site can comfortably be compared to a laboratory type site and conditions
- Restricted access and site conditions allows for lengthy uninterrupted days of data collection under the above-mentioned conditions.

1.6 Summary

Chapter one provided background information, established the aims and objectives, provided justification, identified the problem, the research methods and the solution and confirmed the scope and limitations of the research project. The zero-distance baseline concept and how it relates to real-life practical RTK surveying was explained. The background information detailed point positioning, the effects to RTK due to temporal and spatial error sources, the importance of having an unrestricted view of the sky and it briefly described the transition from the 1996 Survey Operation Manual (SOM) into the current version 7.0 CSR's. The relevance and importance of the transition was not overstated due to the technical content and it provided a definitive historical connection to the past and the steps involved in the dynamics associated with emerging technologies which leads to the current CSR's.

Chapter two will consist of the literary review and provide some limited background on the introduction of RTK into Australia. However, it will highlight with accuracy the Queensland cadastral survey requirements, RTK's inability to be calibrated, and the use of zero-baseline testing, zero-distance baseline testing and time interval window/variations. The review will draw on and highlight previous research from notable sources to demonstrate the importance of this research, provide supporting evidence and demonstrate the historical events that lead this research to this stage.

This research project is the next historical stage in advancing RTK GNSS for cadastral surveying in Queensland. Furthermore, review of literature for this research project will evidence the missing technological gap as well as provide the audience with the necessary knowledge to make informed assessments of the construct of this project and its resultant outcome.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction.

Chapter one establishes the aims and objectives for this research project. To achieve the aims for Chapter 2 a review and analysis of relevant literature will be conducted. Previous research will identify the missing technological gap and the review will reveal the current practices involving RTK. This will provide the reader with the solid platform needed to make informed decisions regarding the information presented in Chapter 3.

The introduction of RTK will be lightly examined. The use of a zero-distance baseline model for testing and analysis of an error budget will be discussed. Sometimes the zero-distance baseline is incorrectly described as a zero-baseline model which is used to verify the specifications of several GNSS receivers simultaneously. This will be clarified but not at length.

Multiple studies have definitively established the accuracy and precision of RTK GNSS (Boey et al. 1996; Emardson et al. 2009; Gibbings & Zahl 2014b, 2014a; Olynik et al. 2002) and further analysis will not be conducted and will only be referred to on an as need be basis. However, little previous research is available to which this research project data results can be compared. In the introduction in Chapter One the zero-distance baseline was explained in-depth and how this project and its results are based, purely, on distances that follow the RTK message around and not on point positions of RTK.

The author acknowledges and notes there is ample previous research relating to RTK accuracy and precisions and accepts there is little comparable research available at the time of completing this dissertation. The literature review is, therefore, hindered and limited because of the lack of relevant research.

2.2 RTK GPS/GNSS

RTK revolutionised the surveying world because it presented the user with an opportunity to survey and establish coordinates, in real time, for points at considerable distance without the need for conventional traversing techniques. By setting the base receiver over a point with 'good quality published coordinates' and, the user utilising the RTK receiver to observe a new point the coordinates of this new point is immediately available. In addition to this, the coordinates of the new point are available in various formats. Initially, there was only one GPS system available and that was the American system.

As time expired other countries developed their own GPS and this prompted the term 'GPS' to be expanded to 'GNSS' (Global Navigation Satellite System). GNSS refers to the collection of the world's global satellite positioning systems. Present systems include the USA's GPS, Russia's GLONASS, China's COMPASS and the European Union's Galileo satellite system. Early in 1994 the first truly automatic, centimetre level RTK system was introduced (Edwards et al. 1999) into Australia. Various Global Positional Systems were available prior to 1994 but not real-time kinematic (RTK) GPS. RTK which requires two GPS receivers allows the user to obtain a point position with centimetre level accuracy in real time.

However, the use of RTK GNSS has continued to increase and, in the author's opinion, research appears commensurate with this increase. The introduction of new satellite constellations provides new improved configurations but accuracy and precision capabilities cannot improve because of the prediction errors that are an inherent component of the signal received by RTK. Certainly, initialisation times are reduced and areas or places where initialisation could not be realised previously and which, effectively, prevented surveys to be undertaken are now possible. These new efficiencies suggest RTK is the preferred method of survey for many applications.

In the opinion of the author, this advancement in technology without an increase in accuracy and precision capabilities suggests that pressure on practitioners to complete surveys in less time is increased. It must be remembered that adherence to survey standards still applies regardless of the method or time efficiency involved in the survey.

The Surveyors Board of Queensland (SBQ) works in conjunction with the Department of Natural Resources and Mines (DNRM) and ICSM to develop, promote and maintain Queensland's cadastral surveying standards and guidelines and, of course the cadastre. The Surveyors Board of Queensland, constituted under the Surveyors Act 2003 administers the Surveyors Act for and on behalf of the appropriate state government Minister for State Development and Minister for Natural Resources and Mines.

In 2012, the SBQ identified that there were concerns relating to practitioners using RTK GNSS inappropriately for cadastral surveys and clarification was required to help practitioners understand and use this technology. Of particular concern was the seemingly potential misperception over the limitations of RTK GNSS, and the accuracies and precisions of derived dimensions. As a result of this issue, the SBQ commissioned the preparation of a guideline (Surveyors Board of Queensland 2012) for the use of RTK GNSS for cadastral surveys.

2.3 Queensland Survey Standards and Guidelines

Queensland's cadastre is of extreme importance to the economy of the State of Queensland and Australia. Therefore, survey standards are a mandatory component of any cadastre and these standards demand compliance if an accurate cadastre is to be maintained and as upgrades are performed. RTK has many varied applications and cadastral surveying is one of those. As per the CSR's, cadastral surveying requires ground distances to be calculated and/or measured and cadastral plans demand ground distance be displayed. The word 'ground' being the operative word. Consequently, the results obtained from this research project have the potential to affect the Queensland surveying standards.

In Queensland, the current cadastral surveying standards is appropriately called the Cadastral Survey Requirements (CSR) and the current version is 7.0 and DNRM has specifically allocated an entire chapter (8) to ensure the new standards are adequately communicated. The CSR is one of a series of standards and guidelines under the Surveying and Mapping Infrastructure Act 2003 (SMI Act).

Section 3.4.2 (Measurement Accuracy) states the accuracy requirement of a cadastral survey in terms of both angular and linear misclose, then goes on to add the requirement that, *All surveyed lines (e.g. boundary lines, connections) must have a vector accuracy of 10 millimetres + 50 ppm. This vector accuracy is at 95% relative uncertainty in accordance with ICSM Standard for the Australian Survey Control Network (SP1 v2.0) (Inter-Governmental Committee on Surveying and Mapping (ICSM) October 2014).*

The following cautionary note by Gibbings, P. & Zahl, M. (2014b) – Using the example in SP#1 version 1.7 (note this version is superseded by version 2.1), page B-27, the standard deviation on a sample line between two RTK points was calculated as 17mm. The 95% confidence interval was 42mm. The surveying standards require 10mm + 50ppm vector accuracy. This requirement then leads to a minimum distance of 640 metres, below which, distances should be measured with a conventional total station, as the RTK measurements do not satisfy the version 6.0 of the CSR's. Version 6.0 of the CSR are now superseded by version 7.0.

Section 8.4.3.1 of the CSR, *Guidance on specific GNSS survey techniques*, provides the practitioner with guidance on real-time kinematic (RTK) technique when using RTK for cadastral surveying to ensure compliance is achieved. The technique highlights the minimum process that requires following if compliance to the standards is to be achieved. Further to this, the following aspects that affect coordinate quality and, subsequently, accuracy and precision are highlighted below;

1. Relative positions can be expressed as bearings and distances but it is important to remember that those are derived quantities and not what is actually measured.
2. Measurements from each receiver are combined with each other and the satellite orbits to compute relative positions between the various antennas,

3. Signals generated by the satellites are measured by the surveyor's antenna and receiver
4. Site dependent effects such as obstructions to the signals, reflected signals (known as multipath and potentially causing decimetre errors) and interference from non-GNSS radio sources cause errors
5. Atmospheric effects due to the ionosphere and troposphere (errors),
6. That quality indicators displayed by the survey controller in the field or in post-processing software can often be overly optimistic because it is based more on internal measurement noise and can underestimate external effects, such as multipath (especially for short occupation times). Therefore, the manufacturer's specification for a given piece of equipment and technique should be used to compute the expected uncertainty of the measurements.

As can be seen above, all of these factors have significant relevance to this dissertation. However, it must be noted that the 'time or time window' between observing points at either end of a line for which a distance needs to be derived has not been given any relevance or considered in depth which provides further support for this research project. The new Chapter 8 of the CSR, version 7.0, is the result of research and subsequent release of two articles by Gibbings, P. & Zahl, M. (2014b) and the release of the SBQ guideline for use of RTK for cadastral surveys (Surveyors Board of Queensland November, 2012). The SBQ implemented this guideline in its entirety in November 2012.

2.4 Calibration of GPS/GNSS

Every researcher agrees GNSS systems are not capable of calibration (Stewart et al. 1998) (Manning, Steed & SDI 2001) (Dickson 2012) and any prescribed accuracies and precisions are only achievable under favourable conditions. Günther Retscher (Retscher 2002) suggests the baseline accuracy of RTK GPS measurements are usually described by a constant and a distance dependent error, e.g. 5-20mm ±1-2ppm. RTK accuracy is defined as the degree of conformance of an estimated RTK position at a given time to a defined reference coordinate value (or "true" value) which is obtained from an independent approach, preferably at higher level accuracy (Feng & Wang 2008).

Conventional survey instruments operate autonomously, are self-reliant and this makes them capable of calibration. Simply put, an Electronic Distance Measuring device (EDM), a terrestrial instrument, sends an electromagnetic signal to a reflective prism and the signal is returned. Instruments of this type are subject to the current medium conditions, namely, temperature and pressure, which the signal must pass through on its way to and from the reflective prism.

These parameters are input into the instrument prior to conducting a survey at that time. The time taken for the signal to reach the prism and return is timed and the distance is mathematically calculated by the instrument based on the speed of light. Originally, before leaving the manufacturers factory the instrument is placed in a vacuum and the signal pulse sent to a reflective prism. The signal and its return is timed in the vacuum and the time multiplied by the speed of light in a vacuum and divided by two. The only variables that exist in real life for the actual instrument is the changes to the climatic conditions.

Unfortunately, GPS is subject to a variety of external influences that can and do change regularly and, as such, causes it not to be self-reliant. The influences (sometimes referred to as biases) that contribute to the inability of GPS to be calibrated, are anomalies in the GPS control and space segments, ephemeris errors, clock errors, satellite geometry, multipath, ionospheric and tropospheric delays (Satirapod & Chalermwattanachai 2005). These biases, when amalgamated, form an error budget. An error budget is a summary of the degree and causation of statistical errors that aid in approximating the true errors when accumulated.

This makes it extremely difficult, if not impossible at times, for the practitioner to ensure their process is compliant. Once the signal is accepted, projection, coordinate system and datum errors have potential to denigrate the survey quality further. Arguably, these can be controlled or corrected by certain processes by the practitioner and could be classed as a human error factor which will not be considered in this dissertation.

Any and all of these biases can and do affect the accuracy and precision of RTK GPS observations. Accuracy and precision of RTK GPS is also distance dependent, meaning assumptions are made that both the base station receiver and the rover receiver are simultaneously experiencing the same errors. This decreases the integrity of RTK GPS observations and adds to the overall error budget although this can be minimised if using a continuously operating reference station (CORS) (Snay & Soler 2008) and/or a virtual reference station (VRS) (Ong Kim Sun & Gibbings 2005). Integrity being a measure of the performance of the GPS system.

GPS does not have a warning system to alert the user of the above biases, instead, it relies on the practitioner to ascertain the level of accuracy and precision being achieved under the current and ever-changing conditions. Multipath is undetectable if multiple base stations are not utilised. If a single base station is being used, relocation of the base to a new previously measured point is required and re-observation of the previously measured points to produce independent and redundant data is mandatory.

2.5 Zero-Baselines and Zero-Distance Baselines

2.5.1 Previous Zero-baseline Method Research

Previous researchers (Edwards et al. 2010; Gibbings & Zahl 2014a; Janssen & Haasdyk 2011b; Odijk, Teunissen & Huisman 2012) have used the zero-distance baseline method for analysis purposes. There are many variations of how the zero-distance baseline method can be used. Some researchers compute the arithmetic mean, average the data into pre-determined averaged datasets and, next, subtract these averaged datasets from the mean to produce distances which are corrected height and expressed in metres. This method produces results that indicate, statistically, that the data improves with time. It could be suggested the results from this process, when graphed, produce an inverse curve ($y = a*1/x$) that flattens out to be asymptotic.

Gibbings and Zahl's (2014a) method only uses the arithmetic mean once and that is to validate the original data and while the results are based on chronology and a moving average the data when graphed is linear in nature. The following paragraph, taken from the introduction in Chapter 1, has purposefully been reproduced to re-iterate to the reader on how the zero-distance baseline method used in this dissertation is applied.

Put into a simple context, the zero-distance baseline accepts that the RTK observations are random and the distances are calculated between the observations as they ‘wander’ around. To elaborate, if we observe a position now, we achieve a set of coordinates (say -26° 30’ 00”, 150° 30’ 00”) computed by the data recorder setup parameters e.g. average of 5 epochs. We wait 30 minutes and re-observe the same point and achieve coordinates of say, -26° 30’ 30” & 150° 30’ 30”. The difference between these two coordinates is the zero-distance baseline (a distance expressed in metres in a one dimensional form – latitude and longitude) and, obviously, because of the temporal and spatial errors associated with RTK the coordinates of the same point ‘wander’ around within the normal RTK error budget. This research project accepts the normal RTK error budget and concentrates more on how the practitioner can work with it. No one observation is accepted as the true value for a point. It does not compute a mean of the sample.

Once the validation process is complete, each consecutive dataset is assumed to be the correct true absolute value. Consecutive, time widowed datasets are subtracted from each other chronologically e.g. 6th from 1st. 7th from 2nd, 8th from 3rd etc. This process allows for the random nature of the RTK signal to be monitored and graphed chronologically. Arguably, when demonstrating real-life fieldwork, Gibbings and Zahl’s (2014a) method is more truly representative of what the practitioner is likely to encounter and achieve in their normal work environment. Certainly, it could suggested that the data has a moving average but this is how RTK observations behave. This dissertation will utilise Gibbings and Zahl (2014a) method.

2.5.2 Zero Baseline

Zero-baseline test is a method that may be used to check the manufacturer's specifications and the internal performance of the RTK GNSS measurement system. An advantage of this method is it can be utilised when a three-dimensional network of sufficient accuracy is unavailable (Van Sickle 2011). The test requires two or more receivers to be connected to one antenna (Bakuła, Pelc-Mieczkowska & Walawski 2012) (refer to Figures 7, 8 & 9). An observation is carried out with the divided signal from the single antenna reaching both receivers simultaneously.

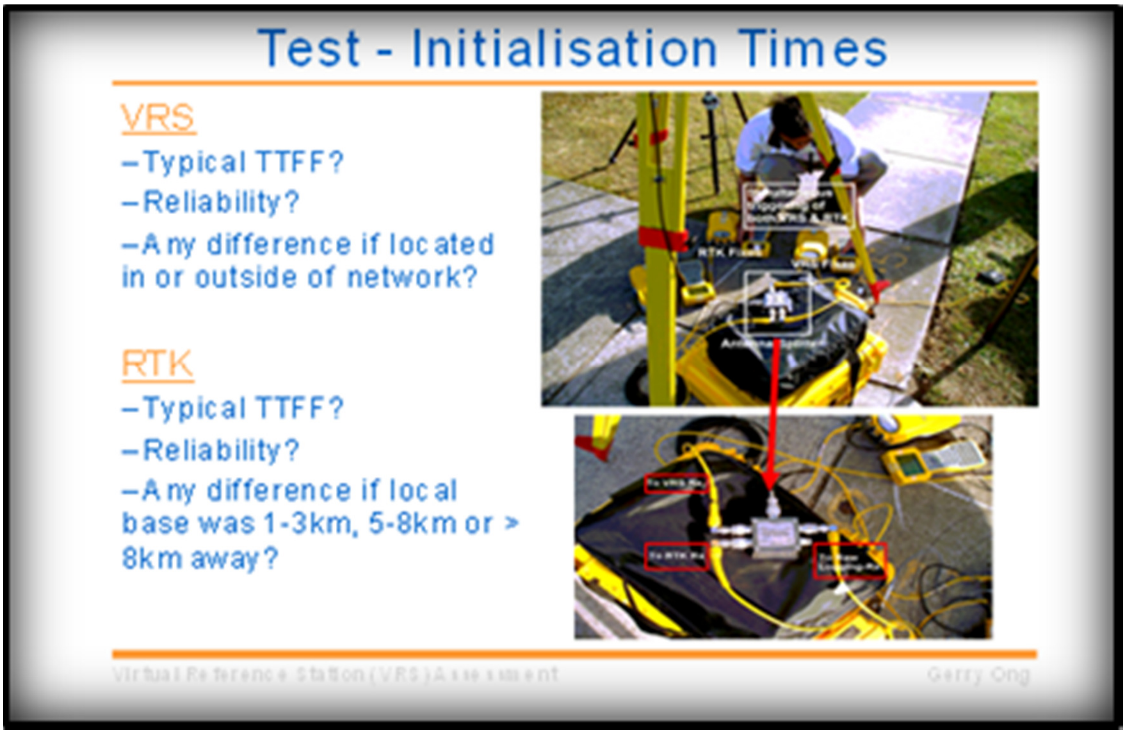


Figure 7: Splitter for Zero-baseline setup

Source: How well does the Virtual Reference Station (VRS) System of GPS Base Stations Perform in Comparison to Conventional RTK? (Sun & Gibbings 2003).

Since the receivers are sharing the same antenna, satellite clock biases, ephemeris errors, and multipath are cancelled out (Van Sickle 2011). The results of the test should show a baseline of zero and at worst only a few millimetres. This system is not employed or referred to anywhere else in the document.

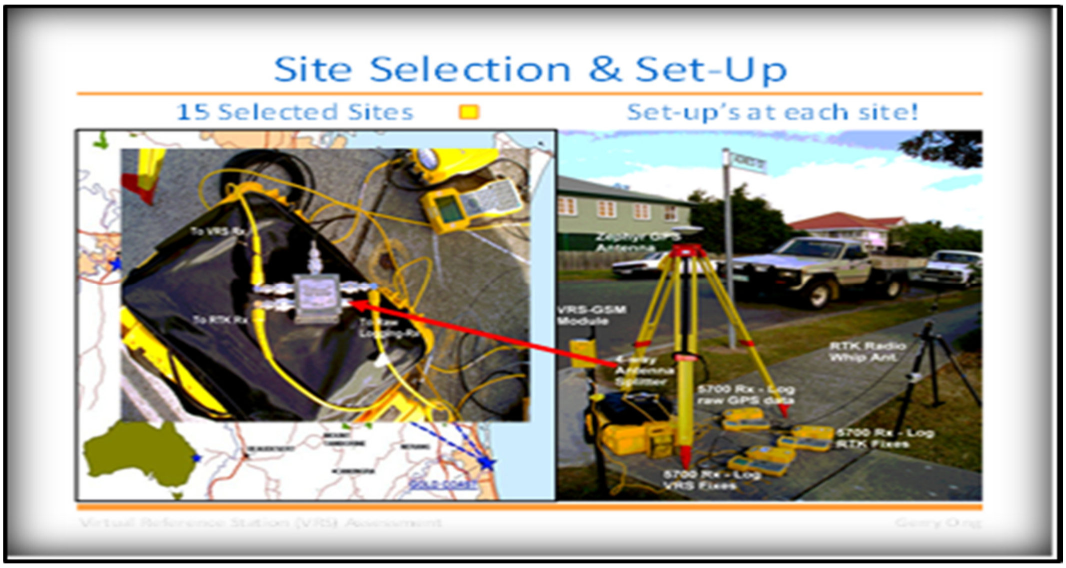


Figure 8: Splitter and Geodetic Antenna setup

Source: How well does the Virtual Reference Station (VRS) System of GPS Base Stations Perform in Comparison to Conventional RTK? (Sun & Gibbings 2003).

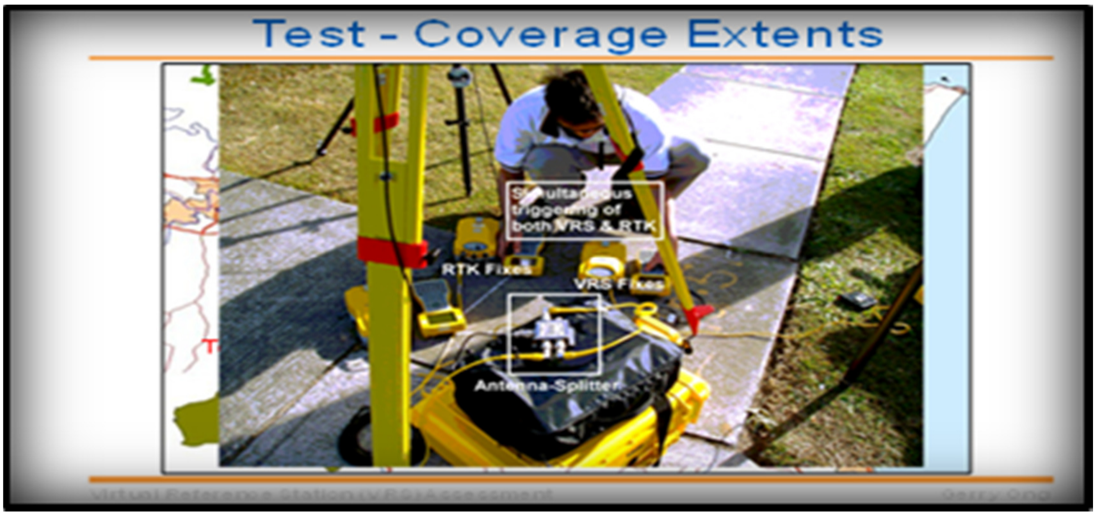


Figure 9: Simultaneous triggering of both VRS & RTK

Source: How well does the Virtual Reference Station (VRS) System of GPS Base Stations Perform in Comparison to Conventional RTK? (Sun & Gibbings 2003).

2.5.3 Zero-Distance Baseline

Zero-distance baselines are not a new concept (Gibbings & Zahl 2014b; Janssen & McElroy 2013; Odijk, Teunissen & Huisman 2012; Victorian Government 1997) (refer Figure 10). It is paramount the RTK rover and base receivers be held completely stable for the entire testing period, it is preferred the receivers be truly vertical but not essential. Having the base station antenna and RTK antenna close together (refer Figure 11) has two main distinctive advantages; it eliminates the need to assess and assume both base receiver and the RTK receiver are experiencing and are exposed to the same conditions. RTK GNSS is distance dependent but this is controlled onsite by the researcher and, it lessens the likelihood of gross or unwanted errors being introduced. Real-time coordinate solutions are achieved for each single epoch of data for a pre-determined testing period.

Figure 10: USQ Trimble Zephyr Model 2 Antennae

Source: University of Southern Queensland, Engineering and Surveying Building, Z-Block Rooftop.

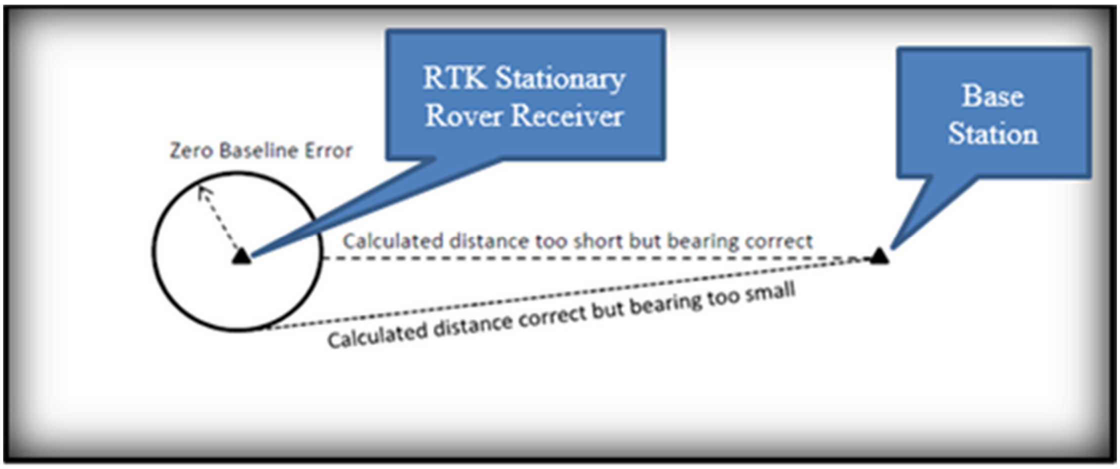


Figure 11: Zero-Distance Error with bearing error included

Source: (Gibbings & Zahl 2014a) When to consider RTK GNSS for a Cadastral Survey.

Figure 11 depicts the zero-distance baseline error schematically. Fundamentally, the base station receiver and RTK rover receiver are held completely stable (immoveable) until a large amount of single epoch data has been collected. Figure 11 shows the RTK rover receiver stationary during the long data collection stage. The mean value is derived via the arithmetic mean of the entire dataset and this value is deemed as true value (most probable value) for the point and outliers (greater than 3σ) and any abnormalities are identified and removed.

In this instance, two hundred and one thousand eight hundred and forty eight (201848) epochs of data were collected and the true value established using this process and validated using the aforementioned process. Next, the 201848 epochs of data are averaged into five second and one minute datasets – 40369 five second and 3364 one minute datasets respectively. Time windows are then introduced. Times windows are the time which elapse between the first and subsequent observations or datasets and, in this case, 5 second and 1 minute averaged sets.

Note Figure 11 because it displays both the distance and angular error. Only the distance residual in single dimensions are considered in this dissertation with the focus purely on the time interval window. Unlike Figure 11, Figure 12 demonstrates the distance residuals only, how they are calculated and why the direction is not used or important to achieve the desired outcome for this dissertation research project.

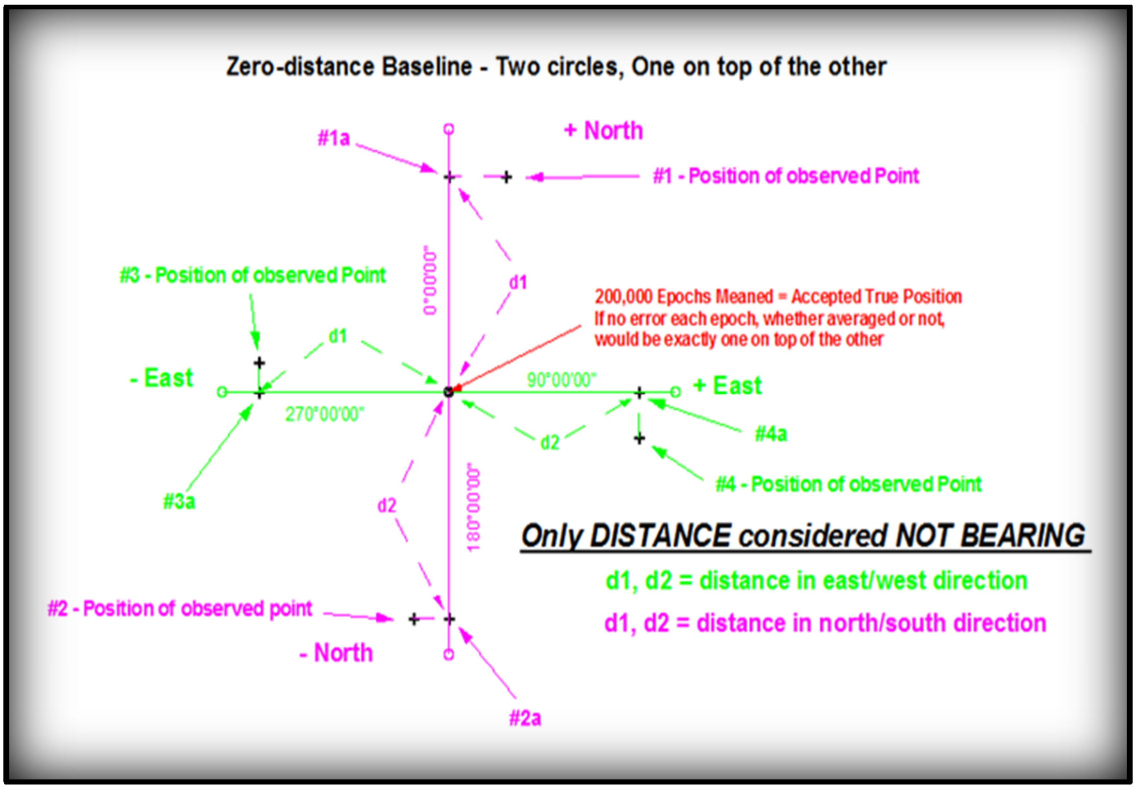


Figure 12: True Zero-distance Baseline

Obviously, the longer the testing period, the more epochs, the more accurate the mathematical determination of the results will be. Arguably, each manufacturer will have their overly optimistic RTK GNSS specifications and quoted accuracies and precisions (Janssen & Haasdyk (2011b); Miller, O'Keefe & Gao 2010) for their individual receivers and systems. Modern RTK GNSS manufacturers generally ignore the temporal correlation (Miller, O'Keefe & Gao 2010) when stating their specifications in technical user manuals or brochures.

However, superscripts or subscripts will be immediately noticeable and will direct the more knowledgeable practitioner and reader to investigate. On investigation the reader will reveal comments such as those listed below;

- Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions.
- The use of stable mounts in an open sky view, no electromagnetic interference and multipath clean environment,
- Optimal GNSS constellation configurations,
- The use of survey practices that are generally accepted for performing the highest-order surveys for the applicable application
- Including occupation times appropriate for baseline length.
- Baselines longer than 30 km require precise ephemeris and occupations up to 24 hours.

Janssen and McElroy (2013, page 2) explain in order to satisfy the strict RINEX standard, all data must be with respect to the phase centre of the physical antenna. This is the reason why the stability of the receivers is paramount. This is called the averaging technique and is often applied to improve the positioning result for real-time applications if the GNSS rover is allowed to remain stationary for a short period of time. Janssen, Haasdyk & McElroy (2012) state averaging mitigates the risk of obtaining a rogue result that disagrees with the actual position by a large amount.

The pre-determined windowed intervals are calculated by averaging a number of epochs. There are many different and varying techniques available to achieve a definitive mathematical result but the aim is ensure the time interval windows relate directly to actual possible surveying conditions even though the testing is undertaken in a very controlled environment and laboratory type conditions.

Trimble GNSS equipment was utilised for the research project but the brand of GNSS equipment is not given any importance because many researchers have used many different brands separately and jointly on many projects (Edwards et al. 1999) (Janssen & Haasdyk (2011b)) (Satirapod & Chalermwattanachai 2005) (Bakuła, Pelc-Mieczkowska & Walawski 2012) and none has suggested one performs better than another. As previously mentioned, it is the aim and objective of this dissertation to assess the time interval windows associated with measuring two points at either end a line to achieve a calculated distance using RTK GNSS not what causes the systems inability to achieve a perfect solution.

2.6 Averaging and Time Interval (Variations) Windows

Chapter 2.5 provided a summary on zero-distance baselines and the advantages of it for use with this project. This chapter will expand significantly on time interval window as mentioned in chapter 2.5.

In relation to time, when using RTK to ascertain the optimum quality position of a point two (2) main factors need consideration. They are; the actual observation time on each point and the length of time that elapses between subsequent ends. These are generally controllable by the practitioner though not always. The need for double occupations are well established (Edwards et al. 2010; Janssen & Haasdyk (2011b)) and are best practice for many surveying applications, including GNSS observations (Janssen, Haasdyk & McElroy 2012).

Double occupations can detect blunders, like observing on the wrong mark, poor centring or a wrong instrument height. For GNSS, double occupations are also useful to detect the effects caused by incorrect ambiguity resolution or bad multipath conditions (Spatial Policy of Department of Natural Resources and Mines. *Cadastral Survey Requirements* 2015, Version 7.0).

Most errors with RTK can be overcome with redundancies in observations (Janssen, Grinter & Roberts 2011; Surveyors Board of Queensland November, 2012) and redundancy builds proof and confidence in the process which allows the accuracy and precision to be determined. The audience is reminded this project will only involve the observation time on the point and the time interval window that exists between observing two separate points when deriving an RTK computed distance. Accuracy is described as the closeness of a result to the true value and precision is described by the repeatability of the measurement at a certain confidence level (Gibbings & Zahl 2014b).

Ong Kim Sun & Gibbings (2005) undertook testing of the Virtual Reference System and quoted accuracies achieved of ±30 mm at 2σ (95%) confidence interval for point positions. Janssen & Haasdyk ((2011b)) quote 95% of positions from a single-base RTK (rover at various sites from 6 km to 22 km from the base) to have a precision of ±15 to 24mm at 1σ (68%). Analysing the above testing method and results, it must be noted that the point positions were calculated from RTK baselines and not a derived distance between two points nor are there compared to absolute positions. Similarly, neither analysis do not make comparisons or consider the effects of time interval windows when using RTK to derive a distance.

The two time interval windows explored in this project are capable of modification to suit various RTK surveying techniques and individual preferences, remembering it is up to the professional to ensure compliance with relevant standards is being achieved. The testing for this project will be undertaken at the same place, under the same conditions at the same time to eliminate errors that can be generated under field conditions. Therefore, unless the practitioner can reproduce the exact same conditions in the field the results will definitely be of a lesser accuracy and precision than those achieved in the research dissertation. The data collection method, mathematical model and processing strategy will be performed under laboratory type conditions and use time as the primary function.

2.6.1 Averaging

Attention is drawn to Figures 13 to aid the audience to understand and visualise how the epoch averaging process is structured. Once the arithmetic mean or true value for the point is obtained the desired number of epochs are averaged to produce a dataset. A dataset will produce a single latitude and longitude point position and is the distance in metres from the true value (0, 0) in either a 0° or 90° direction. The averaging process for this dissertation will commence with five (5) averaged epochs and progress to sixty (60) averaged epochs which will represent 5 and 60 seconds respectively.

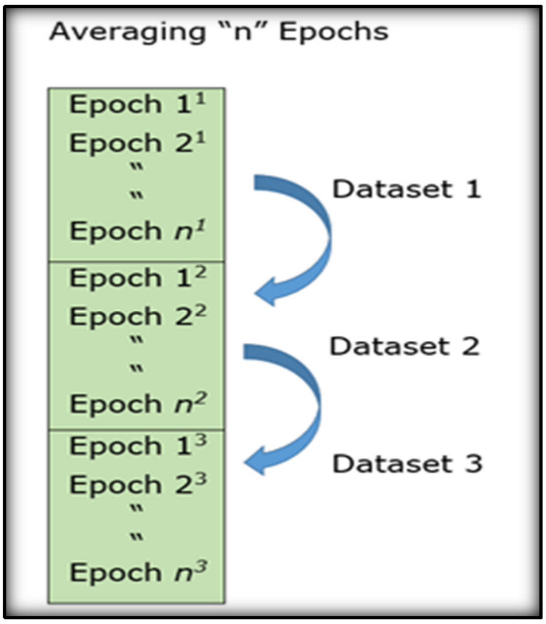


Figure 13: Averaging

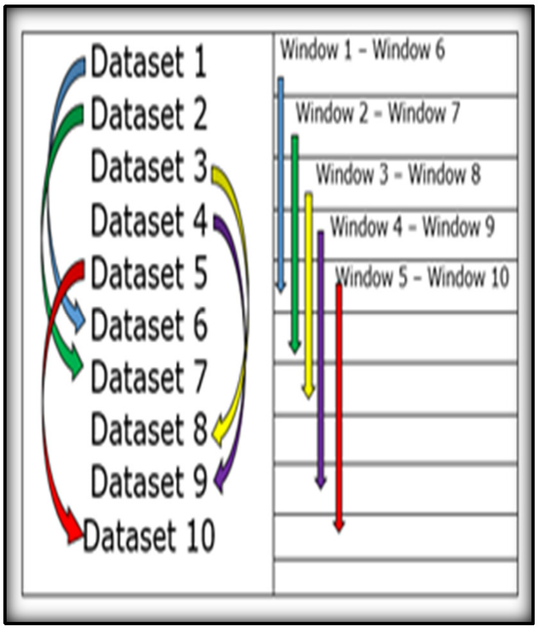


Figure 14: Windowing

2.6.2 Windowing

Figure 14 demonstrates the windowing process. In the pictorial, dataset 6 is subtracted from dataset 1. If a dataset consists of 60 averaged epochs/seconds then dataset 6 is separated by 300 epochs or 300 seconds in time from dataset 1. This, then suggests a time window of 5 minutes has basically expired between observing dataset 1 and dataset 6. Subtracting dataset 6 from dataset 1, produces a single set of latitude (northing) and longitude (easting) distance components in metres.

Principally, we have observed and averaged dataset 1 for 5 epochs or 5 seconds have expired, the, waited 5 minutes and re-observed it again and, next, have achieved a difference between the two datasets from the same point. The next step in the windowing process would be to subtract dataset 7 from dataset 2 and so on.

The 5 second dataset windowed at 3 out to 240 minutes is chosen to establish a baseline to produce patterns, trends and behaviours below which the current CSR standards recommends. The current CSR's recommended minimum observation time is 1 minute and re-occupation in 30 minutes. The 1 minute observation time, (60 second observation time on the point), with 3 out 240 minutes windows will be processed and analysed.

Extensive testing by Janssen, Haasdyk & McElroy (2012) highlights that CQ values do not necessarily represent the actual precision of the position. They further state that the precision is often a lot worse than indicated by the CQ by a factor of 5 to 7. Janssen, Haasdyk & McElroy (2012) are quick to suggest CQ values are often too optimistic and provide an example where a CQ value precision to be 10 millimetres when it is actually much closer to 50 millimetres.

Janssen and Haasdyk (2011) describes the benefit of averaging observations over a window of 1-2 minutes and re-occupying points 10-30 minutes later and suggest adopting the mean of two 3-minute averaged observation windows separated by 20-45 minutes reduce errors by about 5mm. Windowing in this context means windowing or averaging the epochs of data. This process is, in reality, the reverse of the processing strategy in this dissertation.

RTK accuracy was previously defined in Section 2.2. However, due to its importance and relevance to this project and time interval variations demands it be revisited in this chapter. Figures 15 and 16 provide visual definitions for the measures of accuracy.

The three primary measures being; CEP – circular error of probability, RMS – Root Mean Square, 2DRMS – twice the Distance Root Mean Square. Figure 17 provides the necessary connection between the accuracy definitions and probability limits.

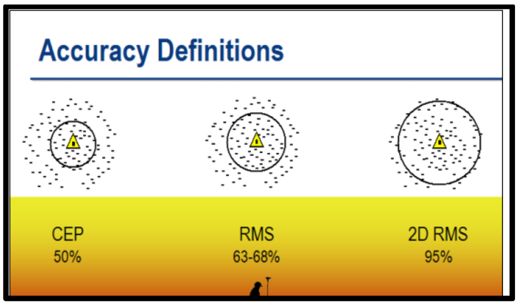
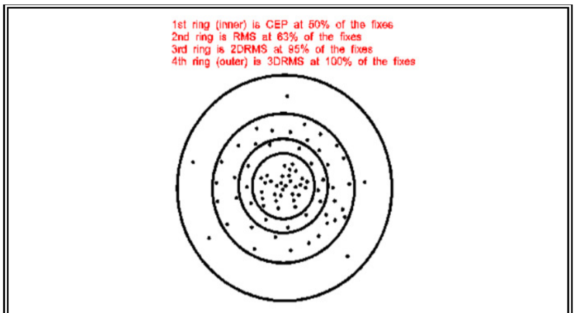


Figure 15: Accuracy Definitions

Source: http://www.spatial-ed.com/gps/gps-basics/133-effect-gps-accuracy.html



Rings of accuracy used to describe GPS horizontal point positioning accuracy. (CLARKE, 1994)

Figure 16: Rings of Accuracy for GPS

Accuracy Measures	Formula	Probability	Definition
DRMS	$\sqrt{\sigma_x^2+\sigma_y^2}$	65%	The square root of the average of the squared horizontal position errors.
2DRMS	$2\sqrt{\sigma_x^2+\sigma_y^2}$	95%	Twice the DRMS of the horizontal position errors.
CEP	$0.62\sigma_y+0.56\sigma_x$ (Accurate when $\sigma_y/\sigma_x>0.3$)	50%	The radius of circle centered at the true position, containing the position estimate with probability of 50%.
R95	$R(0.62\sigma_y+0.56\sigma_x)$ (R=2.08, when $\sigma_y/\sigma_x=1$)	95%	The radius of circle centered at the true position, containing the position estimate with probability of 95%.

Figure 17: Position Accuracy Measures

Source: http://www.novatel.com/assets/Documents/Bulletins/apn029.pdf

2.5 Conclusions

Chapter two introduced the reader, from literature found, to the background of RTK, the Queensland surveying standards, calibration of GNSS, zero baseline testing, zero-distance baseline testing, and averaging and time interval windows. Information from other researchers concluded that CQ values are overly optimistic and that references made to a manufacturer's GNSS technical specification brochures could be construed as misleading.

Comparisons were made between RTK and a conventional instrument and the information advised the reader that RTK does not have an inbuilt warning system. The advantages, as highlighted by reputable researchers (Edwards et al. 2010; Janssen & Haasdyk 2011b), of averaging and windowing data were discussed and the correct interpretation of accuracy and precision were covered.

The time interval windows that the surveyor has some control over was discussed and references to other modern research regarding baseline accuracies and precisions were given. The information also highlighted the technological gap that exists in terms of time interval windows and the lack of recent research providing the reader with a more in-depth understanding of the aim of this dissertation. The information provided a connection between RTK capabilities and limitations to the current surveying standards.

The above précis based on findings from within the literature review provides definitive evidence and justification for this research project.

Next, chapter 3 will consist of the methodology adopted and criteria to be satisfied for the selection of a suitable site, the site credentials, the equipment validation procedure, the use of zero-distance baseline testing technique, the data collection verification process, the data collection method, data integrity evaluation, data processing and computations, the validation of the computations methods and internal mathematics finishing with a conclusion.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 2, the literature review, revised some background information on the introduction of GPS into Australia, the use of RTK GNSS for cadastral surveying in Queensland, calibration, zero-baselines and averaging and time interval windowing. This chapter will provide comprehensive detail on the testing location and facilities, the equipment utilised and the methodology adopted for the data collection process.

Included in the review were some theories and methods relating to the testing of RTK GNSS using zero-baseline techniques. This dissertation is using a zero-distance baseline which is different than using a zero-baseline method. Zero-distance baseline utilises one base receiver and one rover receiver under a very controlled environment. This controlled environment could also be classified as a laboratory type environment except the hardware is located on top of a large building. The aim is to ensure the audience has a very informed knowledge of what equipment was used, how the data was collected and analysed and why such methods were chosen and highlight their relevance and importance to the results and summary.

3.2 Site Selection

For the testing of an RTK GNSS using a zero-distance baseline it is imperative to ensure the site is free of interference from multipath, the point to be used for the testing be extremely stable and the antenna phase centre be securely stabilised and held in one position for an extended period if not always held in its current position. At the University of Southern Queensland (USQ) a permanent continuously operating reference station (CORS), named 'Ananga', and an RTK GNSS receiver/antenna is located on the roof (level 7) of Z-block (refer to Figure 18). Ananga was utilised because it provides a very stable and multipath resistant site which realises an accurate description as a quality controlled external laboratory-type facility with a very friendly GNSS environment because of its unrestricted sky view.

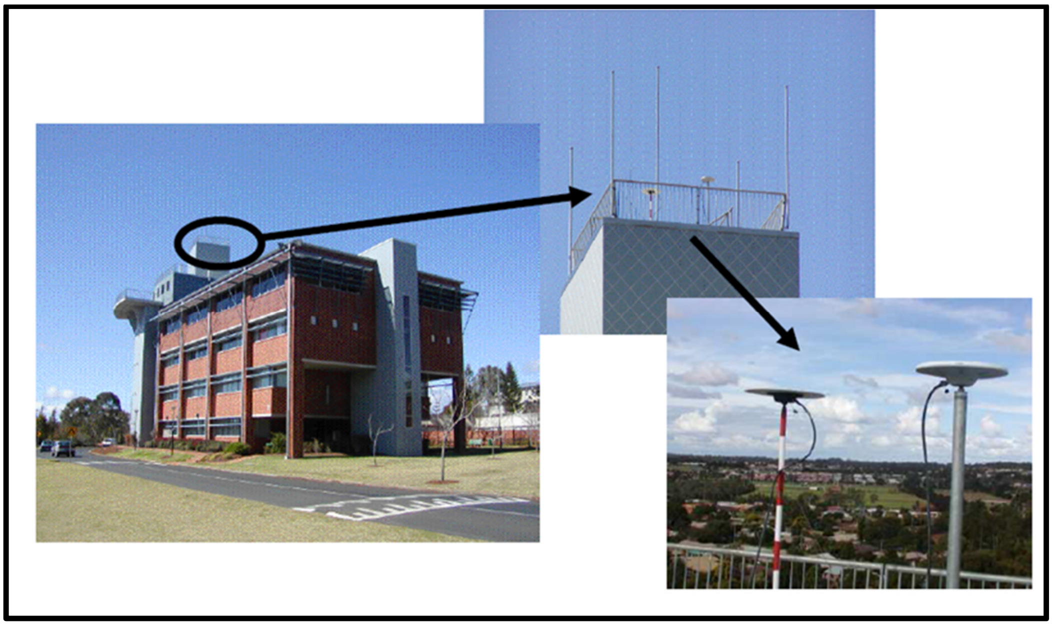


Figure 18: USQ CORS Base Station 'Ananga'

3.3 Base Station, RTK GNSS Receiver and Radio details

Ananga, the USQ base station, consists of a high quality multipath resistant Trimble Zephyr 2 geodetic antenna and a Trimble Net5 GNSS Transceiver and a Trimble 450H radio. The base station antenna is plumbed over a Permanent Survey Mark (painted red and white) with Map Grid of Australia (MGA94) coordinates (refer to Figure 19). The base antenna is secured in place using stay wires.

Figure 19: 'Ananga' CORS PSM

The verticality of any instrument is usually paramount but when using a zero-distance baseline it is more important that the antenna phase centre is held constantly in its starting position for the duration of the testing period. More importance is placed on holding the RTK Rover antenna stable for the complete period of testing because the test involves determining distances between the starting coordinates and subsequent observations and not the comparisons between the absolute coordinates and subsequent observations.

3.3.1 Testing Site

The University of Southern Queensland, Ananga CORS, has been used on numerous occasions for many varied types of research project testing (Gibbings 2002) (Gibbings et al. 2014) (Gibbings & Zahl 2014a) (Ong Kim Sun & Gibbings 2005). The site is workplace health and safety compliant with restricted access and is covered under the USQ Campus Facility Security.

Figure 20: Sky view & Stay Wires

The building is Z- Block at the USQ.

3.3.2 Base Receiver Information Details:

Make/Model:	Trimble NetR5
S/N:	4649K03397
Firmware version:	Nav 3.50/Boot 3.10
Elevation mask:	5 degrees

Tracking interval: 1 sec

Marker Name: Ananga

Station ID: 1

(http://www.trimble.com/infrastructure/netr5-gnss.aspx?dtID=support)

Antenna:

Make/type: Trimble Zephyr Geodetic - Model 2 (Figure 21 & 23)

Model: US National Geodetic Survey Calibration

Setup height: 2.020m to the bottom of the antenna mount

Rebroadcast: via Trimble TDL 450H

There are 5 lightning devices installed and in-line fuses incorporated throughout all cabling systems.

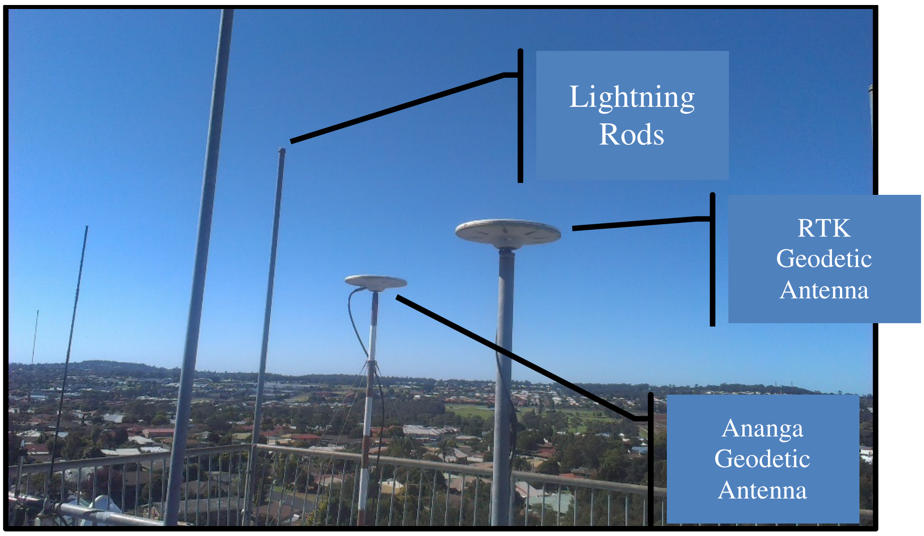


Figure 21: Lightning Rods

3.3.3 Trimble RTK GNSS Receiver Details:

R8 – Model 3 (Figure 22):

Hardware version: 64.3 Software version: 4.44

Boot version: 4.41 Physical SV Channels: 220

RS232 Ports: 2

Tracking:

L2 Capable:	Yes	L2C Capable:	Yes
L5 Capable:	Yes	GLONASS Capable:	Yes
Galileo Capable:	No	QZSS Capable:	No
Beidou Capable:	No		

Internal Radio:

CMR+:	Yes	RTK OTF:	Yes
CMRx Input:	Yes	CMRx Output:	Yes

Figure 22: Trimble R8-3 RTK GNSS Receiver

Figure 23: USQ RTK GNSS Geodetic Antenna

(http://www.trimble.com/infrastructure/zephyr-geodetic-antennas.aspx?dtID=support)

3.4 Site Specifics

The RTK Rover antenna is a Trimble Zephyr Geodetic Model 2 (Figure 23) which is located adjacent to the Ananga base antenna on level 7 of Z-block at the USQ. The antenna is mounted on a purpose built galvanised steel pole and is secured in a constant stable position to the existing steel handrails and stairwell using 'U-bolts'. A GPS Signal Splitter is located in the antenna hut which allows the signal to be received by several GNSS receivers simultaneously (Figure 24).

Figure 24: GPS Signal Splitter
Source: USQ Z-Block

The splitter consists of four ports (J1 to J4) with J1 providing power to the antenna and sending the GPS signal to a Passive Re-Broadcast Antenna (sometimes called a patch antenna) located on the Survey Practical room on the 1st floor (McCabe 2002) (refer Figure 25). A constant ten volt power supply supplies sufficient power, via the splitter to the RTK antenna on the roof, to boost the return signal back to the splitter and then onto the re-broadcaster located in room Z120 located on the ground floor of Z-Block.

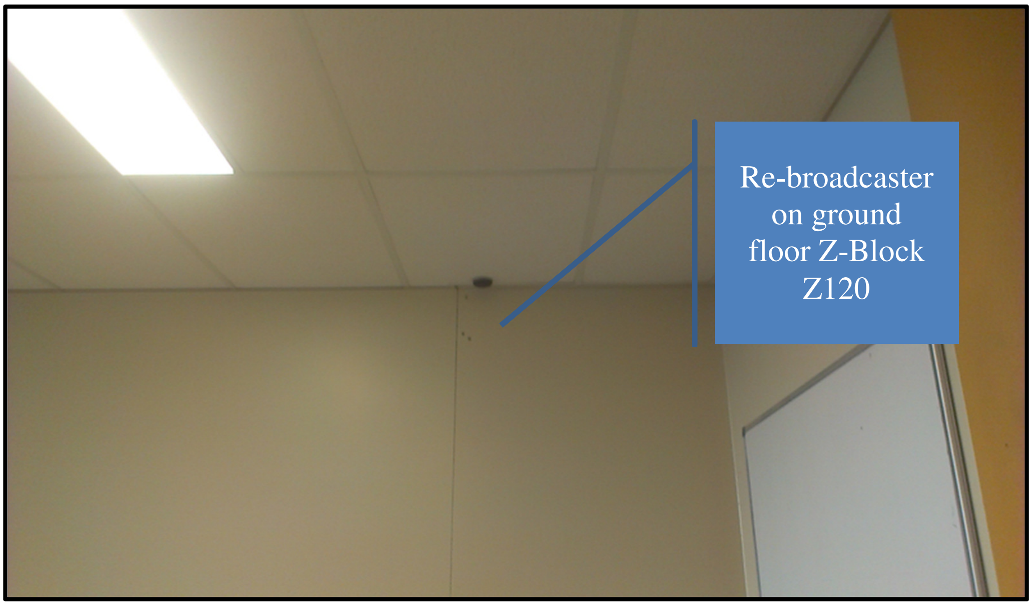


Figure 25: Re-broadcaster USQ Z-Block Z120
Source: USQ Z-Block

The re-broadcaster (ground floor) re-broadcasts the signal to a Trimble R8 Rover Receiver which is connected to a laptop. The R8 captures and sends the signal to the laptop via a data collection cable. The R8 receives the signal as if it were outside in a real-life normal field situation except being inside has many added benefits. These benefits consist of no interference from birds, animals, receiver noise interference and the room is air-conditioned. In the author's opinion, this internal situation provides a better quality environment that an external option.

In terms of data quality, both the base and rover utilise quality geodetic antennae of the same brand and model ensuring there is no antenna bias and both experience the same site specific errors, if any exist, and the data collected is of the best quality available. No data quality is lost as it is transferred through the splitter down to the re-broadcaster where the R8 accepts the signal. The ten volt auxiliary power supply ensures any signal loss is mitigated.

The normal system errors (not systematic errors) that arrive with the signal are also experienced by both the base and RTK receiver. This eliminates any errors that maybe generated as a result of distance. In the field when there is distance involved between the base station receiver and RTK receiver it is difficult to determine what the effect are being experienced at either end. Ideally, to achieve the best results it is advisable to use an antenna of the same brand, type and model for both the base and rover receivers to ensure the physical Antenna Phase Centres are identical (refer to Figures 26, 27 & 28).

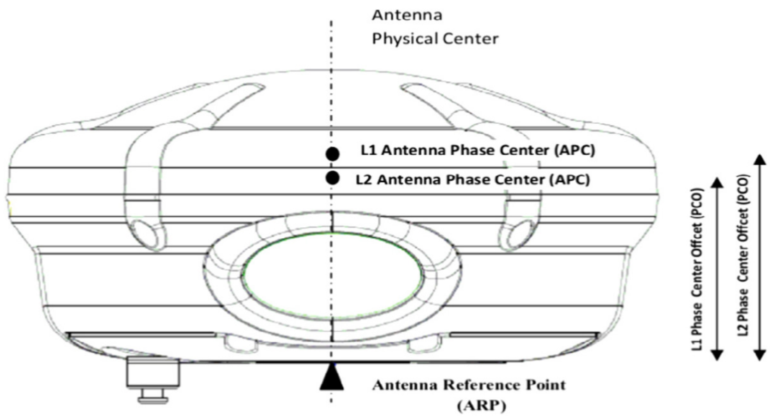


Figure 26: Antenna Phase Centre

http://ac.els-cdn.com/S2090997713000515/1-s2.0-S2090997713000515-main.pdf.

The GPS antenna is the connecting element between the GPS satellites and the GPS receiver. It receives the incoming satellite signal and then converts its energy into an electric current, which can be managed by the GPS receiver. The accurate antenna phase centre offsets' values and phase centre variation factors are critical issues in GPS precise positioning (El-Hattab 2013).

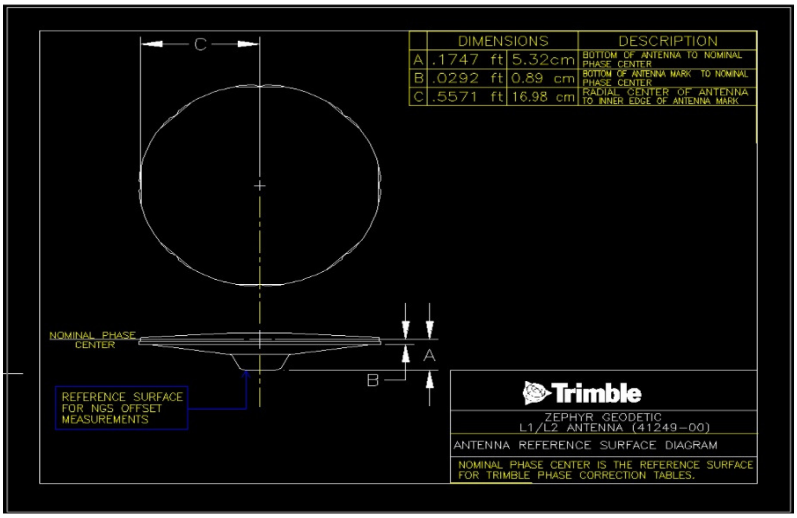


Figure 27: Trimble Zephyr Geodetic Model 2 Antenna

Source:http://facility.unavco.org/kb/questions/240/Trimble+Zephyr+Geodetic+-+Dimensions+(from+Trimble)

Figure 28: Antenna Measurement

Source: http://ac.els-cdn.com/S2090997713000515/1-s2.0-S2090997713000515-main.pdf?_tid=b433663a-0923-11e5-8f21-00000aab0f27&acdnat=1433248645_f9bc89eca4e0ecf1e895d1357356628b

3.4.1 Equipment Validation

The Trimble base receiver is controlled by Trimble GPS Base Software version 2.5 and was used to derive the real-time corrections for the RTK observations. Corrections were received through the CMR+ format via a radio link (Gibbings & Zahl 2014b).

All hardware and software is of geodetic quality and can be validated by comparison to the existing standards for a CORS in Queensland (Inter-Governmental Committee on Surveying and Mapping (ICSM) 2013).

The Trimble TDL 450H radio (Figure 29) is located in a hut on level 5 of Z-block and the antenna is located on level 7.

Figure 29: USQ 450 TDL Radio

3.4.2 Ancillary Equipment

Laptop: Dell

The laptop was checked for functionality and storage capacity before the data collection process.

Microsoft Excel: Version 2007.

Trimble Configurator: Version 5.1.2600.5512 (2004)

HyperTerminal: R8.ht, version 5.1, 2007.

3.5 Using Zero-distance Baseline Testing Method

The zero-distance baseline method is not open to adjustment, manipulation or change. The testing methods' quality and strength comes from its simplicity. That is to ensure both the GNSS base antenna and RTK GNSS receiver antenna are adequately secured to prevent any movement during the testing period under any climatic condition and is protected from outside influences. Access to level 7 of Z-block is very restricted and has several locked accesses to negotiate before direct access could be obtained. This ensured the antennae were not disturbed during the testing phase.

Averaging a large amount of data establishes the best estimate of the truth of the positions' coordinates, then comparing residuals against this absolute standard of truth means the range is not considered or relevant. The range of the residuals will only be relevant when measuring a physical distance.

3.6 Data Collection Verification Process

Chapter 3.5 detailed subordinate and auxiliary equipment. The data collection verification process section will detail the process followed prior to commencing the data collection process. The express intention is to ensure the validity and integrity of the data is protected and maintained throughout the collection process. The method used must be capable of duplication by other professionals and withstand rigorous scrutiny.

On Tuesday the twenty seventh of January 2015, the day designated for the commencement of the data collection phase, the laptop was connected to the RTK GNSS system and test run to identify any abnormalities with software and communication connection issues so they could be eliminated, repaired or re-installed as required.

The parameters were set and connection achieved. The next stage confirmed the data download recording rate of one (1) epoch per second was being realised. HyperTerminal was used as the interface between Trimble Configurator and the laptop.

The final step was to determine if HyperTerminal was collecting and storing the data in the National Marine Electronics Association-GGA-0183 string (hereafter simply referred to as NMEA-0183 GGA string) format. HyperTerminal did connect and was storing data to a text file and with the correct NMEA string. After substantial testing the system came up error free, appeared to start and operate with confidence and the data collection process began at 1655pm on 27 January 2015.

3.6.1 National Marine Electronics Association

The National Marine Electronic Association (NMEA) is an interface standard which permits easily implemented and reliable data communications among electronic marine instruments, navigation equipment, and communications equipment. NMEA-0183 became known as the standard for Interfacing Marine Electronic Devices (Langley 1995). The NMEA-0183 is transmitted at the rate of 4,800 bits per seconds (bps).

The NMEA-0183 Interface Standard defines electrical signal requirements, data transmission protocol and time, and specific sentence formats for a 4800-baud serial data bus. Each bus may have only one talker but many listeners. This standard is intended to support one-way serial data transmission from a single talker to one or more listeners. This data is in printable ASCII form and may include information such as position, speed, depth, frequency allocation, etc. (National Marine Electronics Association 2002) . The data field contains all the data transmitted in a sentence and each sentence has a specified number of fields (Langley 1995).

Decode of selected position sentences

The most important NMEA sentences include the GGA which provides the current Fix data, the RMC which provides the minimum gps sentences information, and the GSA which provides the Satellite status data.

GGA - essential fix data which provide 3D location and accuracy data.

```
 $GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Where:
     GGA          Global Positioning System Fix Data
     123519       Fix taken at 12:35:19 UTC
     4807.038,N   Latitude 48 deg 07.038' N
     01131.000,E  Longitude 11 deg 31.000' E
     1            Fix quality: 0 = invalid
                               1 = GPS fix (SPS)
                               2 = DGPS fix
                               3 = PPS fix
                               4 = Real Time Kinematic
                               5 = Float RTK
                               6 = estimated (dead reckoning) (2.3 feature)
                               7 = Manual input mode
                               8 = Simulation mode
     08           Number of satellites being tracked
     0.9          Horizontal dilution of position
     545.4,M      Altitude, Meters, above mean sea level
     46.9,M       Height of geoid (mean sea level) above WGS84
                      ellipsoid
     (empty field) time in seconds since last DGPS update
     (empty field) DGPS station ID number
     *47          the checksum data, always begins with *
```

If the height of geoid is missing then the altitude should be suspect. Some non-standard implementations report altitude with respect to the ellipsoid rather than geoid altitude. Some units do not report negative altitudes at all. This is the only sentence that reports altitude.

Figure 30: NMEA-0183, GGA Field Code
Source: http://www.gpsinformation.org/dale/nmea.htm

The NMEA-0183, GGA code, structure as seen in Figure 30, will be used as the data collection format. As seen in Figure 30, column 5, the Real Time Kinematic position fix value for confirmation of the fix is 4. Any value less than 4 indicates that initialisation has been lost and the epoch or epochs of data will be neglected.

3.6.2 Data Evaluation/Integrity

To ensure the system was performing as required regular strategically timed visits were made to the ground floor of Z-block where the laptop was held. During these visits the system was stopped and the data text file was saved onto the laptop and copied onto a USB storage memory stick. This was completed to ensure no information was lost. Before leaving the site the previously saved file was interrogated to confirm the amount of data and assess its integrity. The last step was to inspect the laptop to confirm it had started, was collecting and storing data in the NMEA-0183 GGA string format.

A copy of this original file was made and classed as the working file. The data was collated into one spreadsheet giving precedence to the real-time (UTC) collection time. Using this process confirms all the data is processed on a real-time basis.

3.6.3 Data Processing

Section 3.6.2 and 3.6.3 detailed the data collection, evaluation and integrity process. This section will detail the methods used to process the data. Results are not fully evidenced here; instead the emphasis is on the procedural nature of the processing method and strategy so the reader can relate the process to the analysis and the conclusions.

The data was filtered based on the real-time kinematic position fix which is highlighted in Figure 30. The 8257 epoch's which failed this criteria were identified and deleted to ensure they did not influence results.

3.6.4 Processing Strategy

3.6.4.1 Single Epoch Processing Strategy

The processing strategy involves analysing the 201848 single epochs of latitude and longitude. To achieve this analyses, the arithmetic mean of the 201848 single epochs of collected data is determined. Next, each single epochs of latitude and longitude (one dimensional) will be subtracted from the arithmetic mean. This result will then be reduced from ddmm.mmmmm* into metres and then multiplied by a corrected Rho and Nu for the height of the RTK ground position. This is to ensure all distances are represented as true ground positions.

The corrected Rho and Nu values are extracted from Vincenty's Intergovernmental Committee on Surveying and Mapping (ICSM) spreadsheet. Rho represents the radius of curvature of the ellipsoid in the plane of the meridian and Nu represents the radius of curvature of the ellipsoid in the prime vertical and, again, are corrected for height.

The final result, for this process, will produce distance errors in metres from the accepted true value or the arithmetic mean. The single epochs of latitude and longitude distance errors will be graphed and presented separately. This process will highlight any outliers or abnormalities in the entire dataset and aid in validating process. An outlier is defined as any value greater than three standard deviations (3σ) from the mean.

These graphs will form a benchmark or platform for the data from which all other computations and analysis can be compared. This will allow the reader to make informed comparisons and decisions as further processing is undertaken.

3.6.5.2 Five Second Averaged Single Epochs of Collected Data

After confirmation and validation of the data, the complete dataset will be averaged into five second sets of data. This will produce 80666 – 5 second datasets. This is further broken down into 40333 latitude and 40333 longitude datasets. These 5 second datasets will be analysed, graphed and discussed so the reader can establish the second stage of the processing strategy. The reader is reminded to make comparisons with the platform established in Section 3.6.5.1 Single Epoch Processing Strategy.

Next, time interval windows will be introduced. The first window will be at three minutes and increased to a minimum of two hundred and forty minutes and up to seven hundred and twenty minutes as explained in Chapter 2, Sections 2.6.1 and 2.6.2.

These results will be graphed and presented, in several formats, which allows the reader to compare with the single epoch of latitude and longitude collected data benchmark or platform previously established at the outset of the first step in the processing strategy.

3.6.5.3 One Minute Averaged Single Epochs of Collected Data

The final step in the processing strategy is to replicate the procedure in Section 3.6.5.2, Five Second Averaged Epochs of Collected Data, but replace and expand the five second average to one minute or sixty seconds of averaged single epochs of collected data. This will produce 3364 one minute latitude and longitude datasets.

The 3364 datasets of latitude and longitude will be graphed, analysed and discussed singularly. This process with produce another level of benchmarking. Again, at this stage, time interval windows will be introduced, commencing at three minutes and finishing at a minimum of two hundred and forty minutes.

These results will be graphed and presented in various formats so an informed analysis and discussion can take place. There is now a three level processing strategy; a platform to work from, an intermediate step and a final step.

3.6.5.4 Tiers of Processing Strategy

The processing strategy in dot point form;

Step 1

- Compute arithmetic mean (ground coordinates from ddmm.mmmmm* into metres)
- Compute single epochs of latitude and longitude, corrected for height to ensure ground coordinates, convert from ddmm.mmmm* to metres to ensure cadastral distances
- Subtract single epochs of latitude and longitude (metres and ground distances) from the arithmetic mean
- Validate data by identifying outliers greater than 3σ and abnormalities and remove
- Analyse and graph
- First platform set.

Step 2

- Compute 5 second averaged datasets from 201848 single epochs of original latitude and longitude dataset.
- Compute 95% confidence intervals (C.I.) for latitude and longitude
- Graph 5 second datasets of latitude and longitude with relevant 95% C.I.'s
- Compute normal distribution function, statistical analysis and graph
- Second platform set

Step 3

- Introduce time windows to 5 second dataset commencing at 3 minutes increasing and finishing at 240 minutes.
- Compute 95% C.I.'s for 5 second latitude and longitude
- This will produce 40333 latitude and longitude distance error datasets
- Compute normal distribution function, statistical analysis and graph
- Introduce 5 second dataset with the CSR's minimum re-occupation of 30 minutes (5 seconds observation time and wait 30 minutes before re-occupation)
- Graph and analyse
- Compute normal distribution function, statistical analysis and graph
- Third comparison platform set.

Step 4

- Compute 1 minute averaged datasets from 201848 single epochs of original dataset
- This will produce 3364 latitude and longitude distance error datasets
- Compute 95% confidence intervals (C.I.) for 1 minute latitude and longitude
- Graph 1 minute datasets of latitude and longitude with relevant 95% C.I.'s
- Compute normal distribution function, statistical analysis and graph
- Fourth platform set

Step 5

- Introduce time windows to 1 minute dataset commencing at 3 minutes increasing and finishing at 240 minutes.
- Compute 95% C.I.'s for 1 minute latitude and longitude
- Analyse and graph
- Compute normal distribution function, statistical analysis and graph
- Introduce 1 minute dataset with the CSR's minimum re-occupation of 30 minutes (1 minute observation time and wait 30 minutes before re-occupation)
- Graph and analyse
- Compute normal distribution function, statistical analysis and graph
- Fifth comparison platform set.

Finally, conduct a summary of results.

3.6.6 Validation Method of Computations

Vincenty's Intergovernmental Committee on Surveying and Mapping (ICSM) Geodetic Spreadsheet is used to validate the construct of the formulae used in Microsoft Excel to compute the latitude and longitude residual values. Figure 31 displays the longitude residual values computed by using the Inverse Solution spreadsheet between two geographic coordinates. The result being 1.0m at 90º. This indicates the latitude residual value remained at zero and a change in longitude of 1.0m. The starting geographic coordinates (-27º 36' 00.0526503", 151º 55' 54.51299") and a bearing of 90º for 1.0m was then, entered into the Direct Solution as a check for the ending geographic coordinates (Figure: 31).

Both the starting and finishing coordinates were changed into the ddmm.mmmmm format and then, entered into Microsoft Excel. The formulae used to calculate the entire dataset residuals were applied to these coordinates to check if the same residual values agreed with the Vincenty's spreadsheet. Please see figure 32.

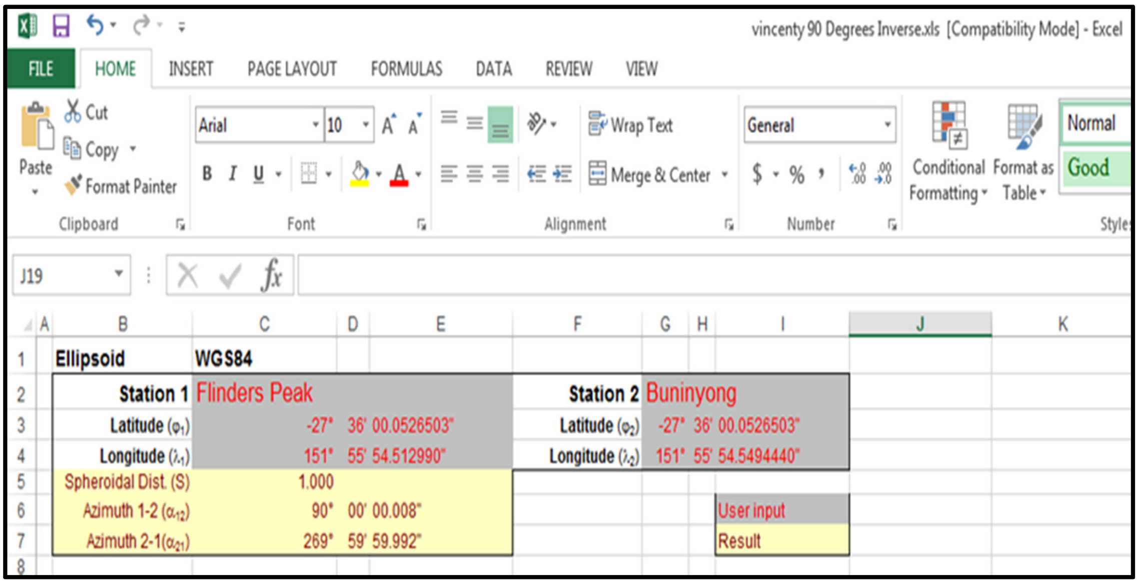


Figure 31: 90 Degrees/1.0m Inverse Solution

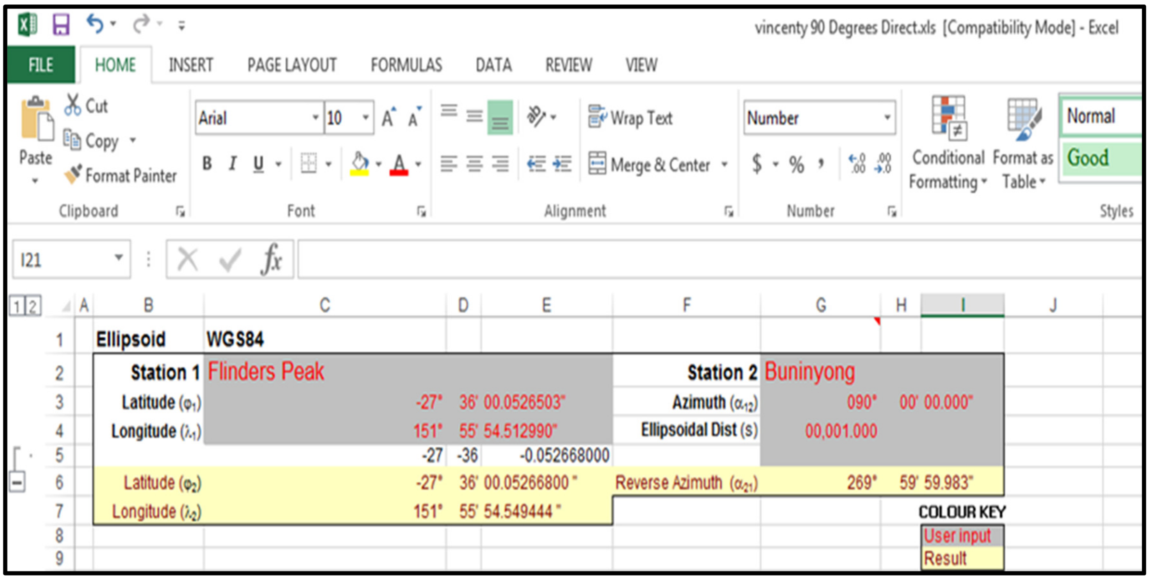


Figure 32: 90 Degrees/1.0m Direct Solution

2736.08720976463	15155.9085498400000	Latitude in Metres	Longitude in Metres
2736.08720976463	15155.9091575525000	0.00000000000	-1.0000000889

Figure 33: 90 Degrees/1.0m Excel Longitude Check

The identical process was followed to check a change in latitude. As seen in figures 33 and 34 the latitude check results are identical in both the Inverse and Direct Solutions in Vincenty's spreadsheet and then, figure 35 provides evidence for the Excel formula for latitude.

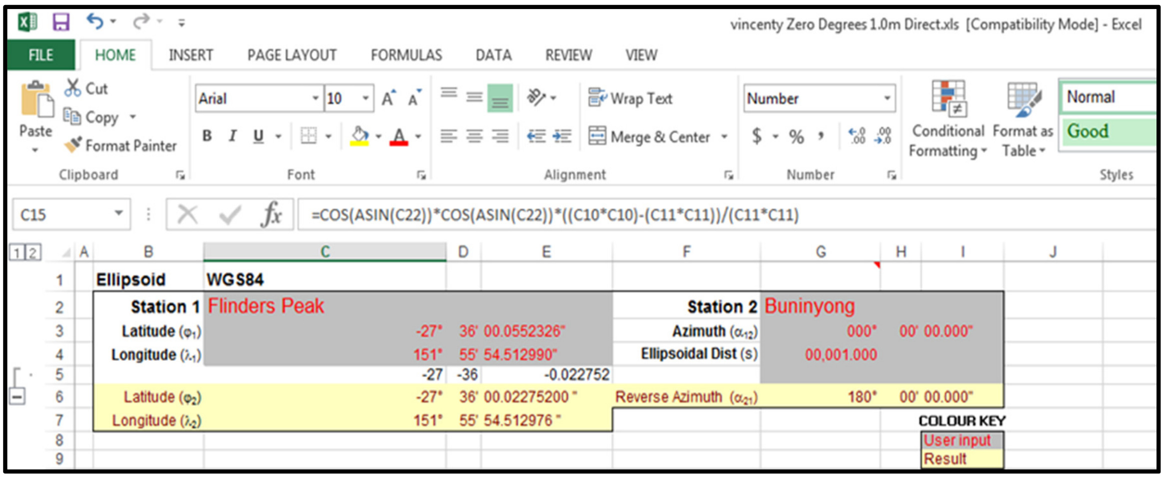


Figure 34: Zero Degrees/1.0m Direct Solution

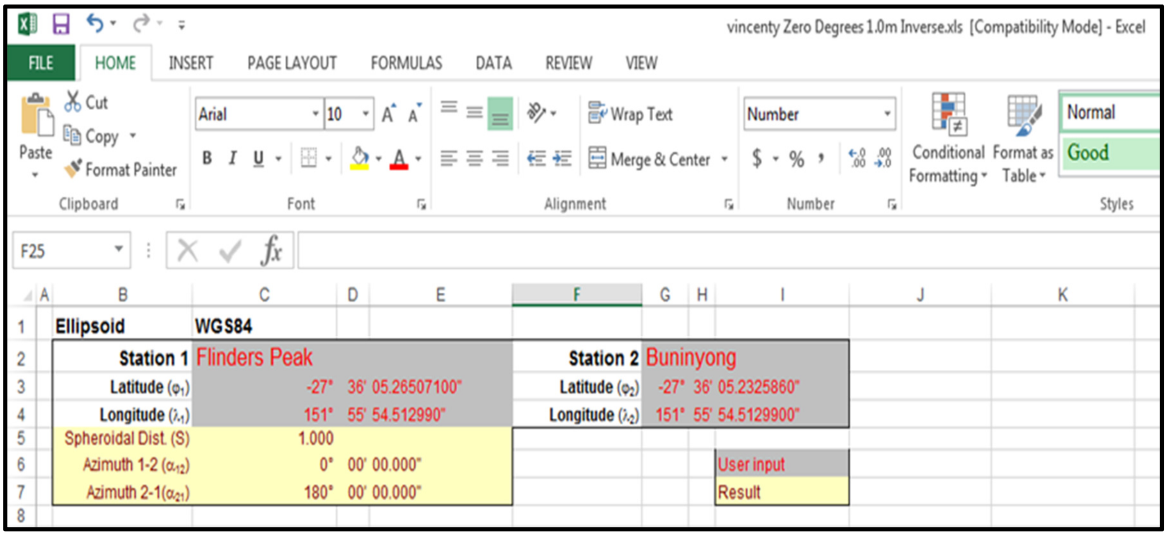


Figure 35: Zero Degrees/1.0m Inverse Solution

2736.08775117703	15155.90854984000	Latitude in Metres	Longitude in Metres
2736.08720976463	15155.90854984000	1.00000001820	0.00000000000

Figure 36: Excel Formulae Latitude Check

3.7 Conclusion of Chapter 3

Chapter 3 provided details on the site specifics, equipment used, the zero-baseline technique, data collection verification processes and data integrity processes. The significance of the site specifics and equipment cannot be overstated because the complete system provides a best case scenario for the data collection process. This is evidenced by the physical distance between the fixed, stabilised high quality geodetic antennae, the multipath resistant environment and its physical location.

The quality of the data collected represents data collected in a perfect world situation suggesting the practitioner, under a normal field situation, would not have the capacity to reproduce data of equal quality. The zero-distance baseline test identified that the mathematical model will produce distance errors which are not distance dependent making the range irrelevant unless a physical distance is measured.
The data collection process was presented in detail, the reader directed to Appendix A for the evidence of the file naming conventions and validation of the formulae is detailed in section 3.6.6. The three tier processing strategy has been detailed and gives the reader the necessary platform from which to build which will aid them in understanding the results and allow them to make informed decisions.

Chapter Four will see the data validated, single epoch data analysis; the five second/ three minute window, one minute/three minute and both datasets (latitude and longitude) processed and analysed starting at the three minute window and increasing to a minimum of the recommended thirty minute delay time before re-occupying the same point. The five second and one minute datasets at the thirty minute time window will be graphed using a linear graph, against the ninety-five percent (95%) confidence interval.

Chapter five will provide an extensive discussion and highlight any potential implications for the impending user and regulatory authorities as seen by the author. Chapter six will see conclusions drawn; a review on achieving the aim and objective, discuss any findings and subsequent recommendations and provide a visionary insight into recommendations for potential future and supplementary research.

CHAPTER 4

4.1 Introduction

The aim of Chapter 4 is to, firstly, validate the research dataset by analysis and then, present the results based on comparisons from previous findings by other notable researcher's (Edwards et al. 2010; Janssen & Haasdyk 2011b; Kim Sun & Gibbings 2005).

Secondly, the five second dataset with a three minute time window at the 95% confidence interval will be analysed to ascertain trends, behaviours, patterns and/or changes to determine if time interval windows affect the accuracy and precision of an RTK derived cadastral distance or determine if there is any deviation from what others researchers' may have experienced. Following will be, the five second dataset with increasing time windows at the 95% confidence interval, commencing at zero time (point positions) and finishing at two hundred and forty minutes. Thirdly, with the intention of mathematically isolating any variable to aid in the answering of the research problem statement which is 'Does time interval variations effect an RTK derived distance.'

Succeeding this will be the one minute observation time at increasing time windows at the 95% confidence interval. The intention is to have the ability to visually interpret the graph and compare to previous pictorials to highlight trends, patterns, behaviours, patterns or changes to such with the aim of isolating any variable, dependent or otherwise. The reader is reminded the main focus is still concentrated on time factors.

Next, the five second and one minute observation time over increasing windows at 95% confidence interval will be graphically explored and supplemented with a numerical table to aid in identification of particular time windows. The chapter will finish will an over view summary before proceeding to chapter five.

Due to the quantity of data being processed and, aid in the interpretation of the results, a series of Microsoft Excel tables and line graphs have been utilised to illustrate the statistical results.

4.1.1 Data Validation

Many researchers (Boey et al. 1996; Emardson et al. 2009; Gibbings & Zahl 2014b; Janssen, Grinter & Roberts 2011; Janssen & Haasdyk (2011b); Olynik et al. 2002; Ong Kim Sun & Gibbings 2005) have empirically established the accuracy and precision of RTK, at varying confidence intervals using various observation times and techniques, and this previous research is used as the baseline to validate the integrity of this data.

Ong Kim Sun & Gibbings (2005) undertook detailed testing and comparisons between a Virtual Reference System and a single base RTK system within south east Queensland. Their distances ranged from 6 to 22 kilometres from the base. On making comparisons between this research project data results and Ong Kim Sun & Gibbings (2005) and Gibbings & Zahl (2014a) it must be noted they achieved their results using what is classed as a zero baseline method. The zero baseline method involves observing the same point, with the same receiver at separate time intervals and deriving a distance (inverse between the same two observations).

Gibbings & Zahl (2014a) quote, in the absence of any measurements errors, two positions observed at the same site should produce a calculated (inverse) distance of zero. However, an assumption is made that the RTK receivers at the individual sites are experiencing the same condition at each end of the line (Gibbings & Zahl 2014a).

Gibbings & Zahl (2014a) cite precisions of three epochs of measurements over numerous baseline lengths as ±30 millimetres at 2σ (95%) confidence interval. They also noted there was a significant increase in the quality of observations between 15 and 60 seconds.

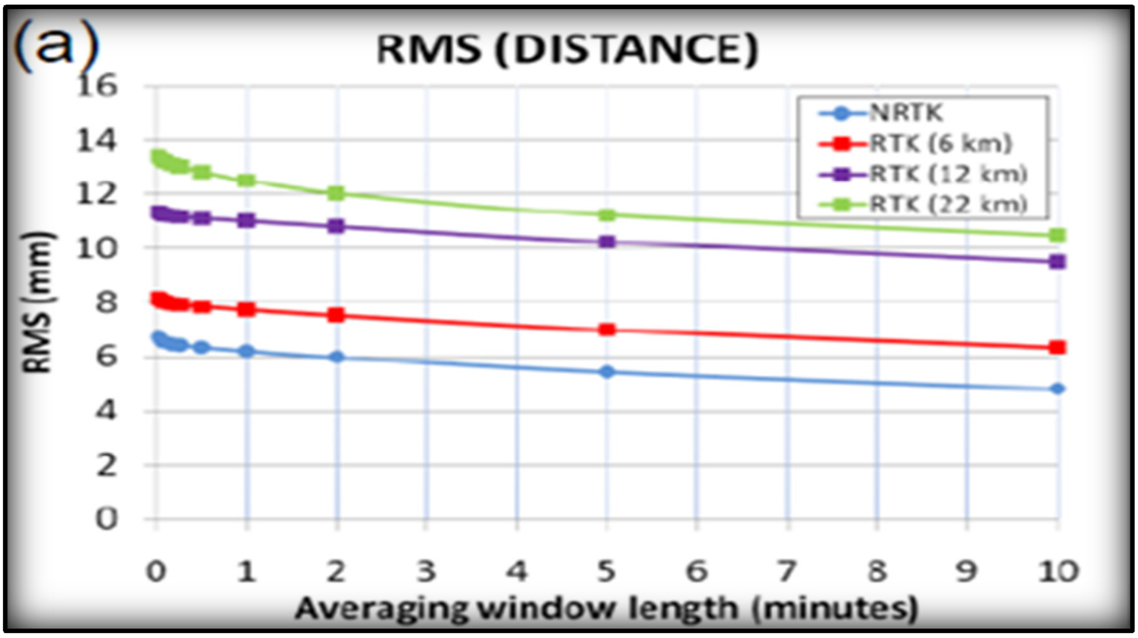


Figure 37: 6km to 22km at 68%
Source: Janssen and Haasdyk (2011b)

Janssen and Haasdyk (2011b), using a single base RTK, achieved a precision of ±15 to ±24 millimetres for 95% of positions (Figure 37 - distances ranging from 6 to 22 kilometres from the base) for three locations. Janssen and Haasdyk (2011b) results are not at 95% but could be used as a guide.

This dissertation collected research data achieved 0.0076m and 0.0082m at 95% C.I. for latitude and longitude point positions respectively. Converting the absolute distances from the mean would produce ±0.0112m in the horizontal component ($\sqrt{(0.0076^2+0.0082^2)}$). These results highlight the laboratory type conditions at the USQ 'Ananga' CORS site under which the research data was collected.

It appears obvious that, the collected research data is not representative of data collected under field-like conditions as Janssen and Haasdyk's data displays. Therefore, the user or practitioner must be aware of the site specific and setup errors associated with real-time fieldwork results.

Janssen and Haasdyk (2011b) also found there was no significant increase in quality when observing for longer than one to two minutes. It is assumed this statement reinforces the fact practitioners want a balance between complying with standards and time efficiency in relation to economic cost efficiency.

The symmetry, behaviour and trends of Janssen and Haasdyk (2011b) data as demonstrated in Figure 37 closely resembles the research project data and, in fact, is almost identical to the collected research data.

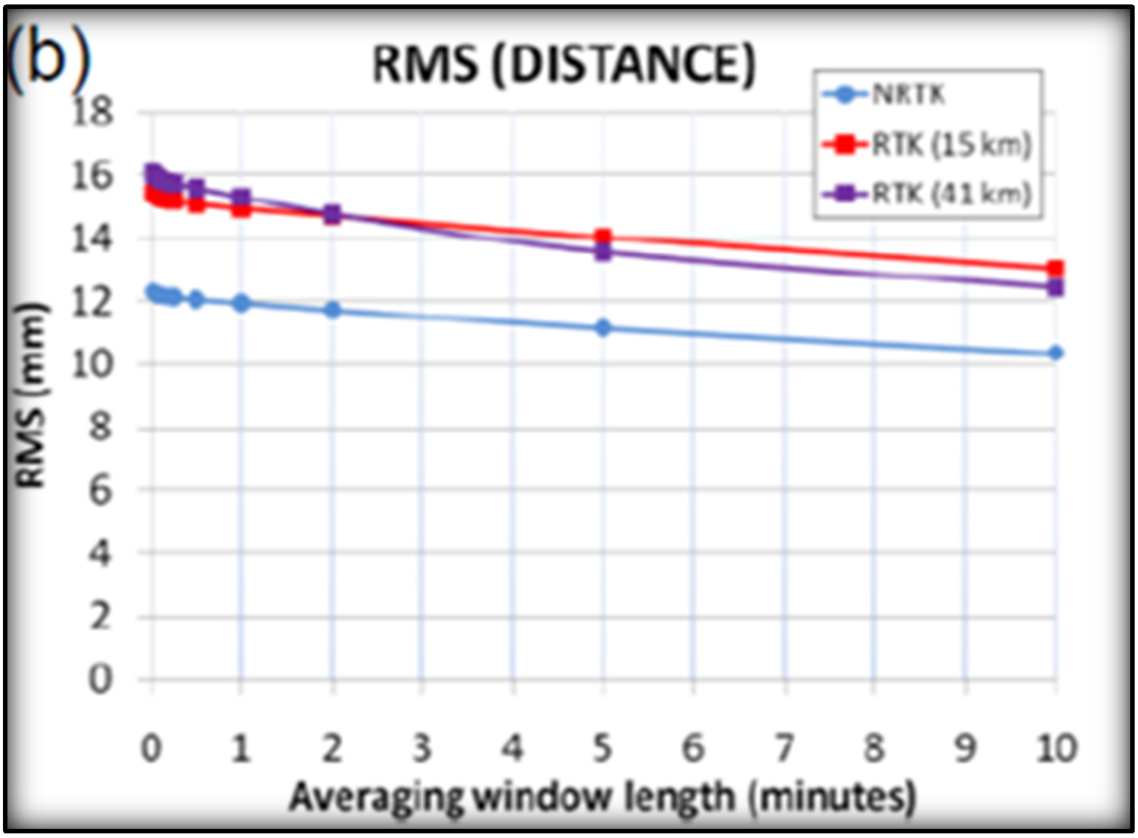


Figure 38: 15km to 41km at 68%
Source: Janssen and Haasdyk (2011b)

Illustrated above in Figure 38 are the results Janssen and Haasdyk (2011b) achieved at the Macquarie University location. Note the range of distances has now increased from 6 to 22 kilometres to 15 and 41 kilometres. As a guide, Janssen and Haasdyk (2011b) achieved ±0.024m at the 24 km distance. This collected research data can only be compared with trends, behaviours and patterns, simply because, the collected research data does not have distance dependent errors. However, the symmetry, behaviours and trend of the graph (Figure 38) closely emulate the project research data collected.

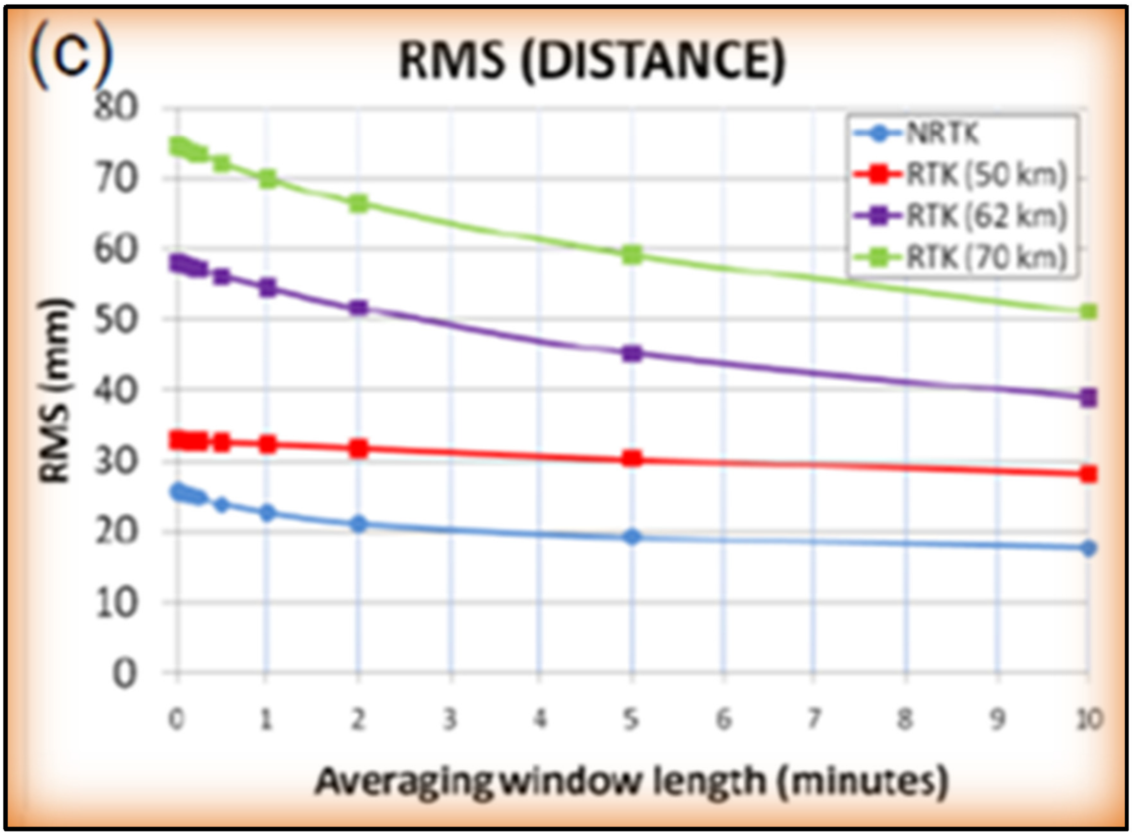


Figure 39: 50km to 70 at 68%
Source: Janssen and Haasdyk (2011b)

Figure 39 demonstrates the results achieved by Janssen and Haasdyk (2011b) at Sofala. The distances are now 50 to 70 kilometres and the results are quoted as RMS (mm). The symmetry, behaviours and trends emulate the project research data results. Note the Network RTK (NRTK) data line expressed in Figures 37, 38 and 39 also emulates the collected research data in terms of trends, shape and behaviour.

Janssen, Grinter & Roberts (2011) quoted accuracies of 11 mm in the horizontal and 34 mm in the vertical at the 68% C.I. with a dual frequency single-base RTK and rover receiver. Their distances range between three (3), twenty eight (28) and thirty two (32) metres. Converting the 0.011m horizontal error into 95% produces 0.027m.

The collected research data achieves 0.0060m and 0.0066m for latitude and longitude respectively. Janssen, Grinter & Roberts (2011) quoted accuracies include errors such as setup and centring errors. It could be assumed, given the short baselines, that the base and rover were experiencing very similar site conditions during the data collection stage. No graphics are available for comparisons with the research project data.

201848 Single Epochs of collected Data results	Latitude	Longitude
2 Sigma or 95% Confidence Interval	-0.0076 metres	0.0082 metres

Table 1: 95% Confidence Interval of 201848 single epochs of collected data

Table 1 illustrates the single epoch descriptive statistics. As seen the latitude and longitude single epoch at ninety-five percent C.I. (95%) of the sample has been calculated, reduced and represented in metres. This is another mathematical demonstration which aids in validating the collected data.

The University of Southern Queensland 'Ananga' CORS station antenna appears multipath free and the close proximity of the geodetic base and rover receiver antennae to one another allows us to safely assume that both are experiencing identical ionospheric and tropospheric conditions. The setup errors are eliminated; specifically there are no centring or height errors because stayed single poles are used. The antennae are attached to a round steel pole which is welded to a flat metal plate with pre-drilled holes. These plates are securely held in position using concrete dyna-bolts through the plate and into a substantial concrete building and then, stabilised in position using wire laid steel cable coupled with turnbuckles to ensure appropriate tension is applied to hold the receivers when in the correct position.

This demonstrates the research data is of a higher quality than previously described research because of the laboratory type conditions of the University of Southern Queensland CORS site. It must be mentioned that climatic conditions at the time of data collection was clear, fine and cloudless days.

The collected research data does behave very similar to previous researchers' data and therefore, this is a demonstration that there is unlikely to be any hidden problems. Figures 37, 38 and 39 simulates analogous trends as the project research data. The above discussion, analysis and comparisons to previous research demonstrate this research data has no apparent loss of integrity or validity. This validation authorises a continuation of the processing strategy which is to further analyse the project research data, to obtain an empirical answer to the research question.

4.1.2 Single Epoch Data Analysis

The first step in processing and analysing the data is to ascertain what the collected single epochs of data represent. The zero-distance baseline method will be utilised and, at this stage, it is assumed the single epoch analysis will provide the least accurate and precise results. This process involves computing the arithmetic mean and subtracting the single epochs of latitude and longitude from it. The resultant ddmm.mmmmm* geographic coordinate values will be converted into metres and corrected for height to ensure the point positions are ground-based in metres. The lack of averaging and windowing will produce point positions only and no distance errors between windows will be calculated. In general, it can be stated that the analysis will be statistical and for validation of data integrity only.

Table 2 exhibits the range for latitude and longitude which is -0.0643m and 0.0661m respectively, for the entire 201848 epochs of data at ground level. These figures are a direct result of the temporal changes that affect the broadcast signal prior to its arrival at the receiver end. The degree of range for both latitude and longitude is quite significant.

Single Epochs of 201848 Point Positions.	Latitude	Longitude
Range	**-0.0643m**	**0.0661m**

Table 2: Range of Single Epoch Latitude and Longitude Point Positions

When applying the zero-distance baseline method a circular error ellipse is produced as opposed to the normal oblong error ellipse when two and three dimensional values are used in the determination of an error. In this particular instance, the zero-distance baseline involves establishing an arithmetic mean of the entire sample of 201848 single epochs of data and this value accepted as being the true absolute coordinates for the point. Next, the single epochs of collected latitude and longitude data is subtracted from the accepted true coordinate values.

This process produces a difference in two position errors (latitude and longitude) and the results of this is the latitude will be expressed in either a north or south direction (0^o or 180^o) and the longitude in the east or west direction (90^o or 270^o). Any direction could have been chosen but these values were chosen to represent a simple Cartesian plane. Any application of the Pythagorean Theorem (√ (x2 + y2)) will produce a magnitude and direction which is self-explanatory given the nature and structure of the Pythagorean Theorem formulae. However, the direction or bearing error is ignored and, therefore, is considered outside the scope of this research and not discussed.

201848 Single Epochs of collected Data results	Latitude	Longitude
2 Sigma or 95% Confidence Interval	-0.0076 metres	0.0082 metres

Table 3: Latitude and Longitude single-epoch 95% confidence interval of the Point Positions.

As seen in Table 3, the latitude and longitude single epoch's 95% C.I. of the sample has been calculated, reduced and represented in metres.

Table 4 displays the values for Rho (p) and Nu (v) respectively before and after correction for height. The height correction is performed to ensure any distances presented and discussed are true ground distances. Rho is the radius of curvature of the meridian and Nu is the radius of curvature in the prime vertical of the spheroid. The corrected radii was extracted from Vincenty's formulae from the Intergovernmental Committee on Surveying and Mapping (ICSM) website.

	Rho(r)	Nu (n)	
$\Delta\varphi R = \ell$	6348900.847	6349590.137	$\Delta\lambda\, v \cos\varphi = s$
Corrected fo Height	6349590.137	6383340.509	Corrected for Height

Table 4: Rho & Nu corrected for Height at that Point

The graphs from Figures 40 and 45 were derived from computing point positions. To achieve this, the arithmetic mean for latitude and longitude of the 201848 single epochs of data was computed and, next, each single latitude and longitude single epoch point position was subtracted from the arithmetic mean. As previously mentioned, this result was converted in metres which represents a distance in either a north/south (latitude) or east/west (longitude) direction from the arithmetic mean. Figures 40 (latitude) and 41 (longitude) depicts the random nature of the single epoch observations.

It is worth noting the visual representation of the range, its random nature, in both latitude and longitude, and the fact it never appears to stabilise and at this scale the distances appear to be randomly distributed with no easily discernible pattern, and with few outliers greater than three sigma or 99% C.I.

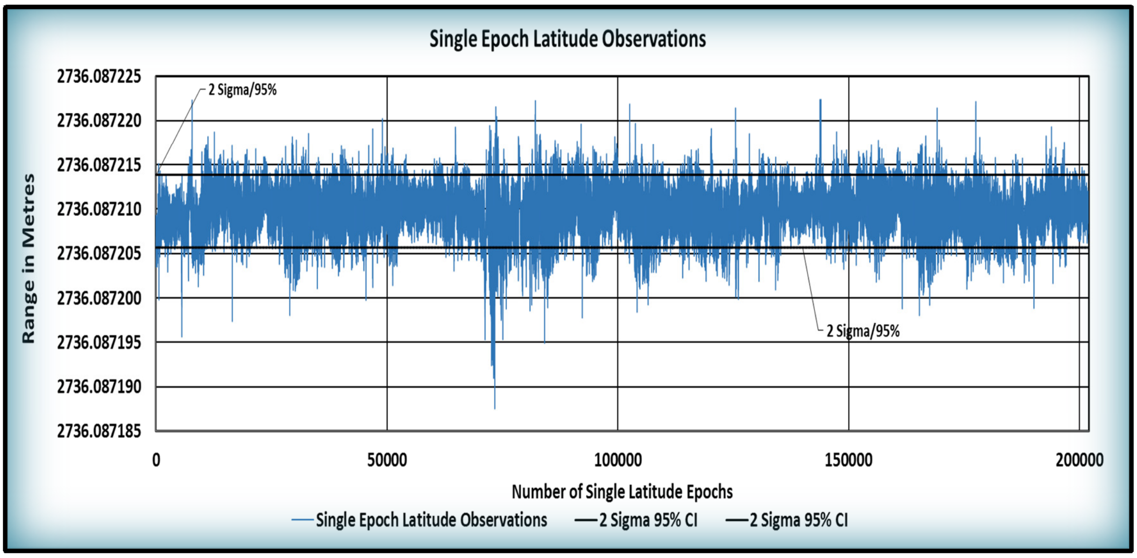


Figure 40: Latitude Point Position Range with 95% C.I. of dataset included.

The intention of the plots in Figures 40 and 41 is to demonstrate the fact, that there are no noticeable trends between latitude and longitude single epochs and highlight the fact the range, accuracies and precisions are comparable in nature. The processing strategy also depicts the accuracy of the computed solutions as a function of observation time and, again, the lack of convergence behaviour or correlation between the latitude and longitude distance errors. Thus, it can be stated that the single epochs of data are, at some stage and before any further processing, displayed as highly scattered with a normal distribution and with very little or no correlation.

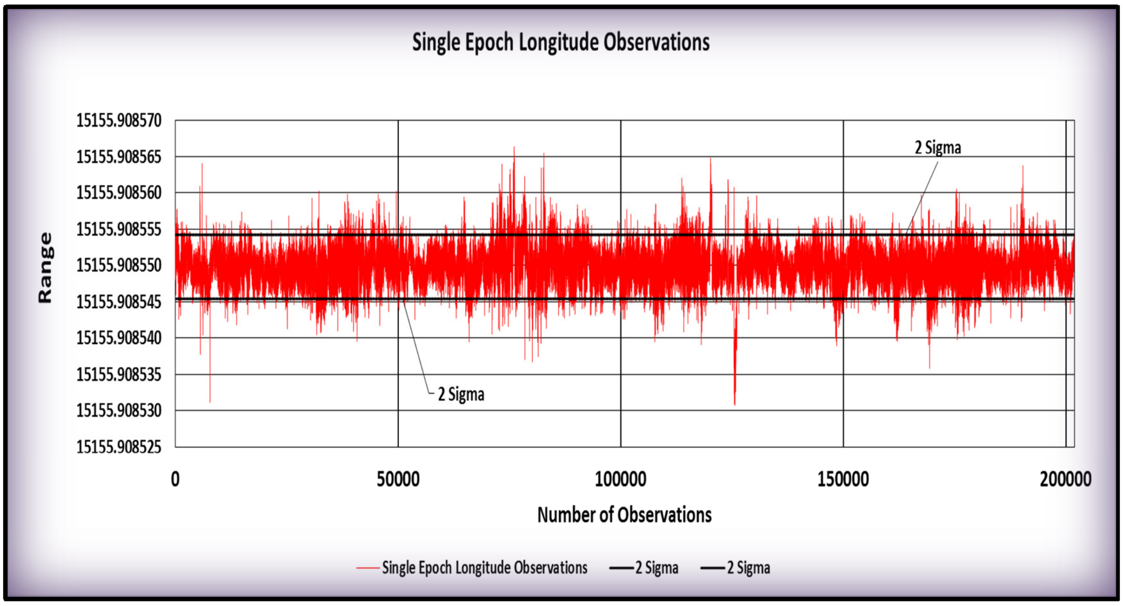


Figure 41: Longitude Point Position Range with 95% C.I. of the dataset

4.1.3 Single Latitude Epochs Defined

The 201848 single epochs of collected latitude data was graphed (see Figure 42 histogram) and demonstrates the almost normal distribution of the single epochs of latitude.

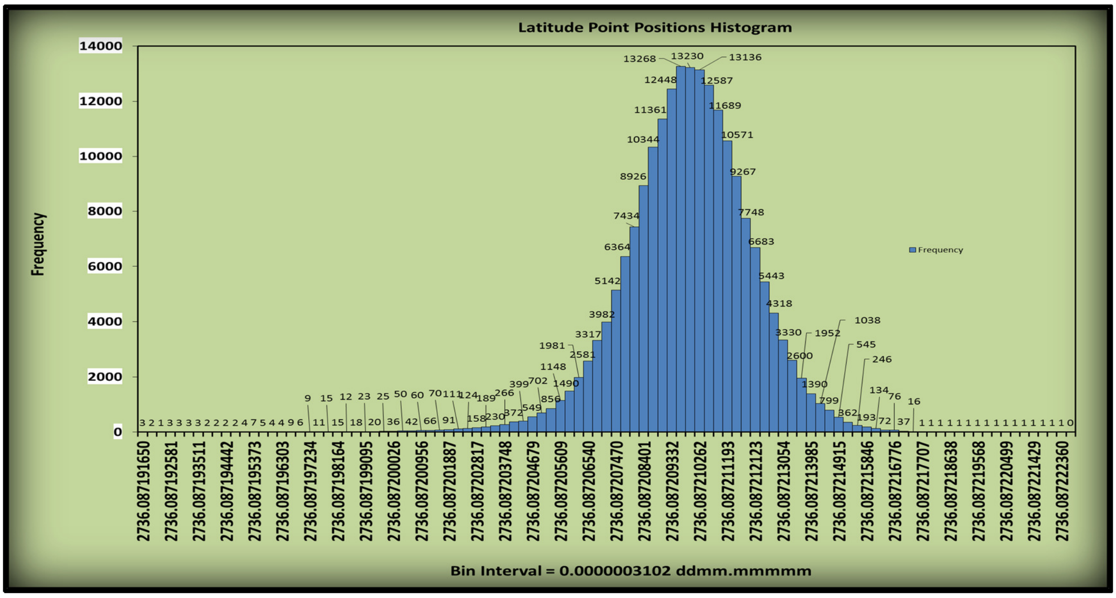


Figure 42: Single Epoch Latitude Point Position Histogram

Latitude	
Mean	2736.0872097452
Standard Error	0.00000000464938
Median	2736.0872098
Mode	2736.0872096
Standard Deviation	0.00000208885202
Sample Variance	0.00000000000436
Kurtosis	2.132748
Skewness	-0.438149
Range	0.00003482
Minimum	2736.08718754
Maximum	2736.08722236
Sum	552273731
Count	201848
Largest(1)	2736.08722236
Smallest(1)	2736.08718754
Confidence Level(95.0%)	0.00000000911268

Figure 43: Single Epoch Latitude Point Position Descriptive Statistics

The results from the descriptive statistics of the single epoch latitude observations are depicted in Figure 43. The range, Figure 43, of 0.00003482 ddmm.mmmm* when converted equates to 0.0643 metres which confirms the previous latitude calculations (Table 2) and its variability.

4.1.4 Single Longitude Epoch Defined

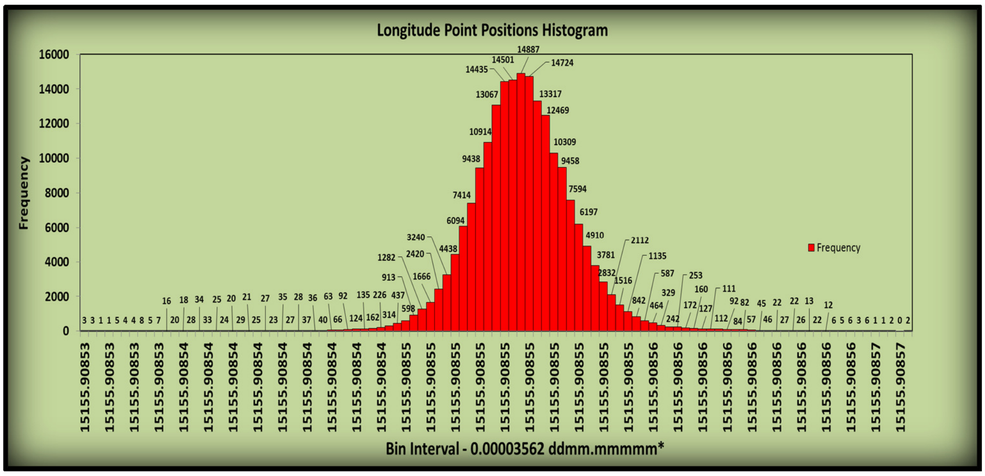


Figure 44: Single Epoch Longitude Point Position Histogram

The results expressed in the Figure 44 histogram displays a visual interpretation of the research project single epoch longitude data and its closeness to a normal distribution.

Longitude	
Mean	15155.908549902
Standard Error	0.00000000050006
Median	15155.90854985
Mode	15155.90854969
Standard Deviation	0.0000022466
Sample Variance	0.0000000000005047
Kurtosis	4.359691
Skewness	-0.074829
Range	0.00003562
Minimum	15155.908530780
Maximum	15155.908566400
Sum	3059189829
Count	201848
Largest(1)	15155.9085664
Smallest(1)	15155.9085308
Confidence Level(95.0%)	0.000000009801

Figure 45: Single Epoch Longitude Point Position Descriptive Statistics

Figure 45 demonstrates the descriptive statistics for the single epoch longitude observations. The range, 0.00003562 ddmm.mmmm* when converted to metres equates to 0.0661 metres as seen in Table 2 which confirms the original calculations.

4.1.5 Notes

	Latitude	Longitude
Mean – Median	**-0.0001m**	**0.0001m**
Mean - Mode	**0.0003m**	**0.0004m**
Median - Mode	**-0.0004m**	**-0.003m**

Table 5: Single epoch Point Position collected data mean/median/mode differences.

Table 5 represents the differences between the latitude and longitude mean, median and mode. The closeness of these values contribute to the validity of the data by suggesting no noticeable outliers or blatant abnormalities exist. Note these values are expressed to a 10000th of a metre. This also demonstrates that both latitude and longitude are very close to a normal distribution.

The intention of the plots and computations was to demonstrate and reveal the positioning accuracies, precisions and behaviour of the single epochs of latitude and longitude and verify the validity and integrity of the original dataset. It has done this.

4.2 Five Second/Three Minute Window Dataset at 95% Confidence Interval

The next step in the processing strategy is to critically analyse the results of the predetermined averaging and time windows commencing with the 5 second dataset at the 3 minute window. The results achieved from the 5 second/3 minute window for the latitude and longitude computations will be displayed, analysed and discussed simultaneously. The processing strategy commences with a five (5) second single epoch average and a three (3) minute window which will be referred as 5s/3m from this point forward (see Figure 46).

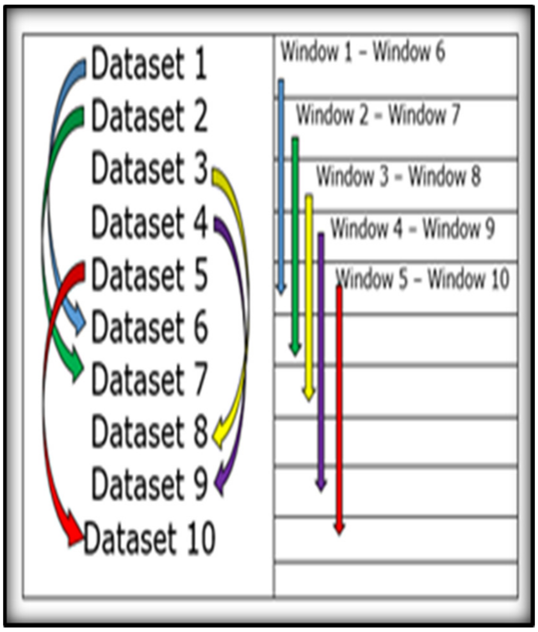


Figure 46: Windowing Effect

Applying the 5s/3m strategy produces a total of 80666 calculated zero-distance baseline distances, each which is stated in terms of its latitude and longitude components in metres, 40333 distances in latitude and 40333 in longitude. There are 5 second less distances because we have progressed down the 5 second averaged epoch list by 3 minutes than previously stated in Chapter 3, Section 3.6.5.2 which quotes 40369. These distances are expressed in metres and are a distance in a north/south (latitude 0°/180°) and east/west (longitude 90°/270°) direction.

The three minute window is achieved by subtracting the sixth (6th) 5 second dataset from the first (1st) 5 second dataset. Effectively, 300 seconds have expired between the first and sixth datasets. In a field scenario, we would observe the point for 5 seconds or acceptable epochs, wait 3 minutes, and then re-observe the same point for 5 seconds. Observing the same point in 3 minutes is effectively measuring the opposite end of a line to derive a cadastral distance in a field scenario.

5 Second/3 Minute Distance Errors		
Number of Distances 40333	Latitude- Distance Error in Metres	Longitude - Distance in Metres
Maximum	0.0274	0.0286
Minimum	-0.0220	-0.0069
Standard Deviation of the Sample	0.0035	0.0033
95% Confidence Interval	0.0069	0.0064

Table 6: Descriptive Statistics for 5 second/3 minute window dataset

Table 6 illustrates the descriptive statistics for the 5s/3m latitude and longitude distance expressed in metres. The 5s/3m latitude range distance has improved from 0.0643m (Table 2) to 0.0494m and the longitude from 0.0661m (Table 2) to 0.0355m. Averaging and windowing data does reduce the effect of extreme, short-lived outlier observations, but can still produce results that are significantly offset from the mean (Janssen, Haasdyk & McElroy 2011c). Note the range for both latitude and longitude has reduced.

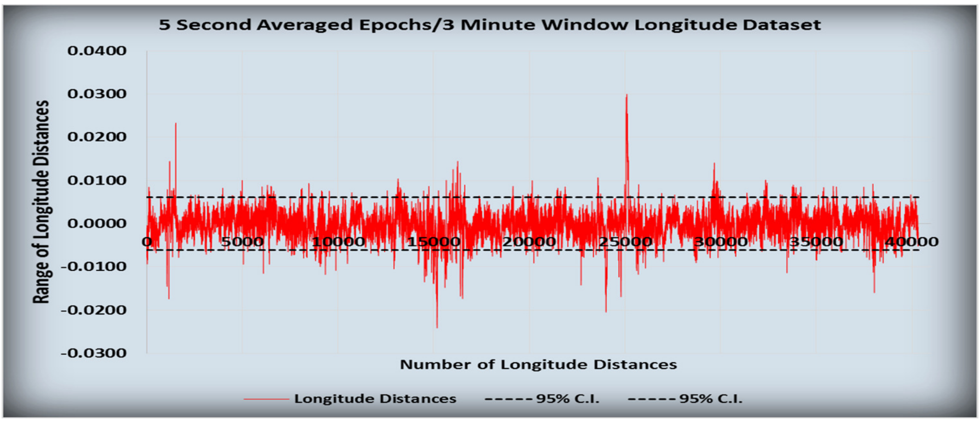


Figure 47: 5 Second/3 Minute Longitude Distance Errors with 95% C.I.

Figure 47 and 48 provides a pictorial of the 5s/3m dataset of 40333 longitude and latitude residual distances and the 95% C.I. of 0.0064m and 0.0069m respectively. The influences and effects of the temporal characteristics associated with the GNSS broadcast message are well demonstrated.

The effects of averaging and windowing the single epochs of data are also evident. In fact, there is an improvement in the 95% C.I. of 0.0007m in latitude and 0.0013m in the longitude 95% C.I. The 95% C.I. of the single epochs of data for latitude and longitude was 0.0076m and 0.0082m respectively as seen in Figures 46 and 47.

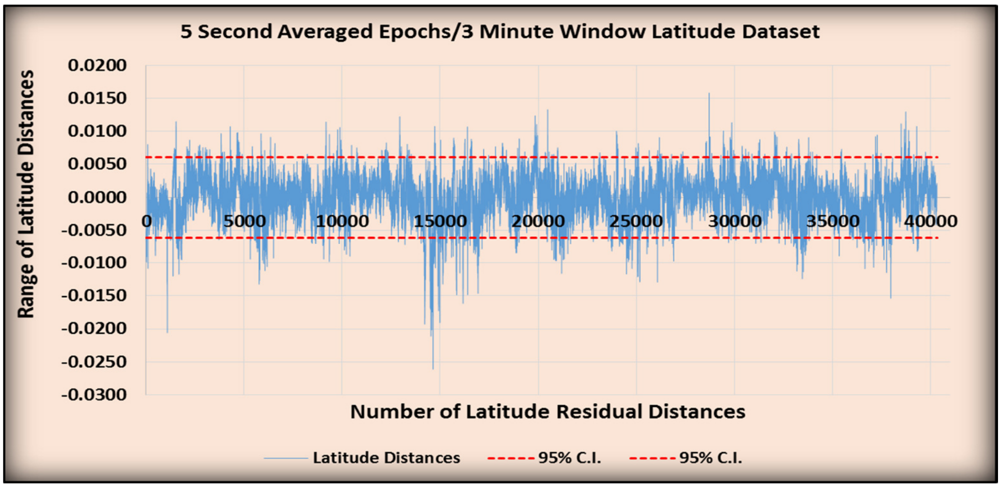


Figure 48: 5 Second/3 Minute Latitude Distance Errors with 95% C.I.

Inspection of Figures 49 (latitude histogram) and 50 (longitude histogram) suggests both latitude and longitude are close to being normally distributed.

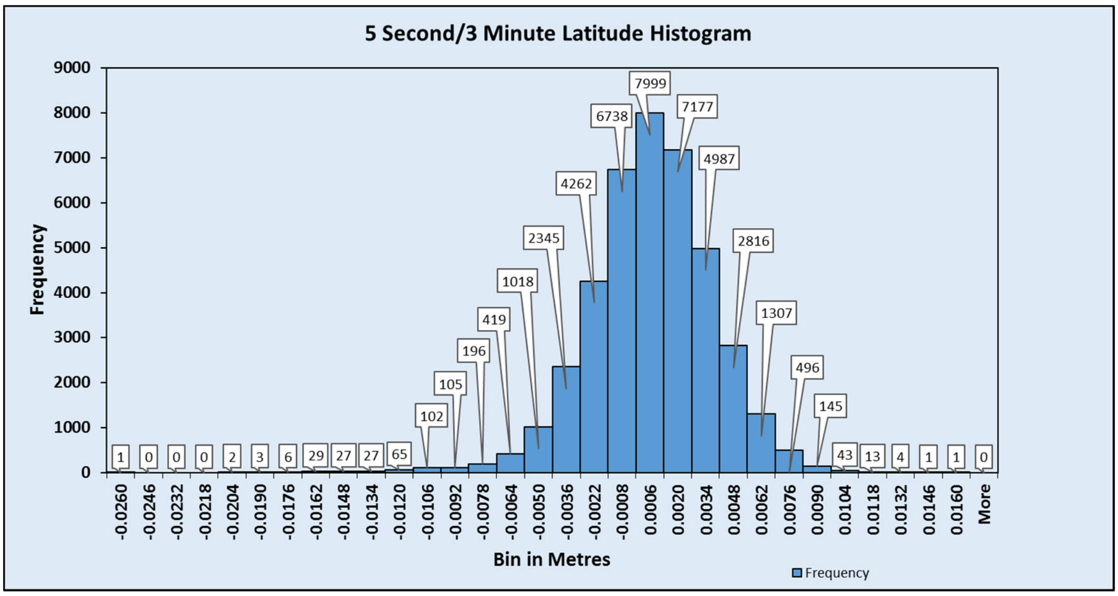


Figure 49: Latitude Distances Histogram

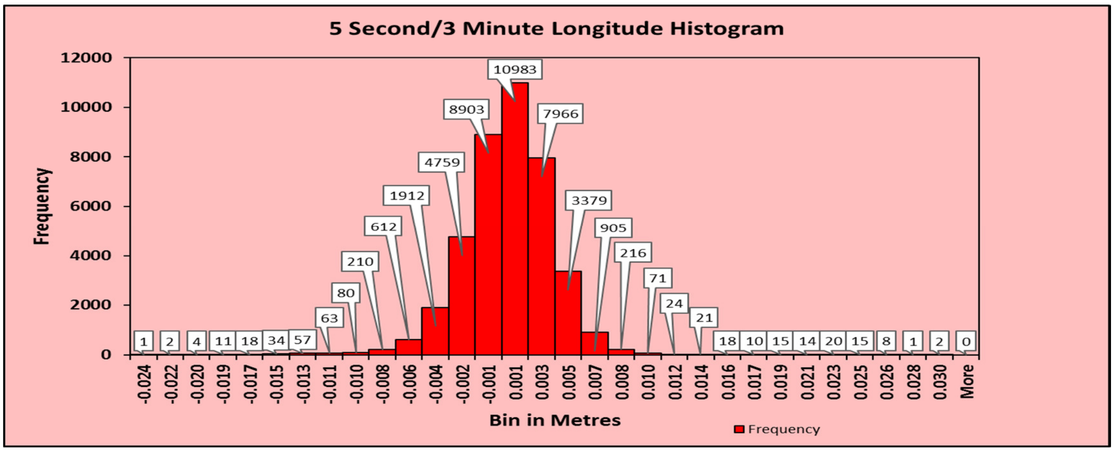


Figure 50 : 5 Second/3 Minute Longitude Distance Histogram

As previously mentioned, the mathematical model and processing strategy (Chapter 3, Section 3.6.5.2) utilised to define the 5 second/3 minute dataset is inferring the original statistical single epoch data range and 95% C.I. has improved. Next, to ascertain if specific trends or behaviours exist within the 5 second observation time on the point, an analysis will be conducted using increasing time windows.

4.3 Five Second Observation Time with Increasing Windows at 95% Confidence Interval

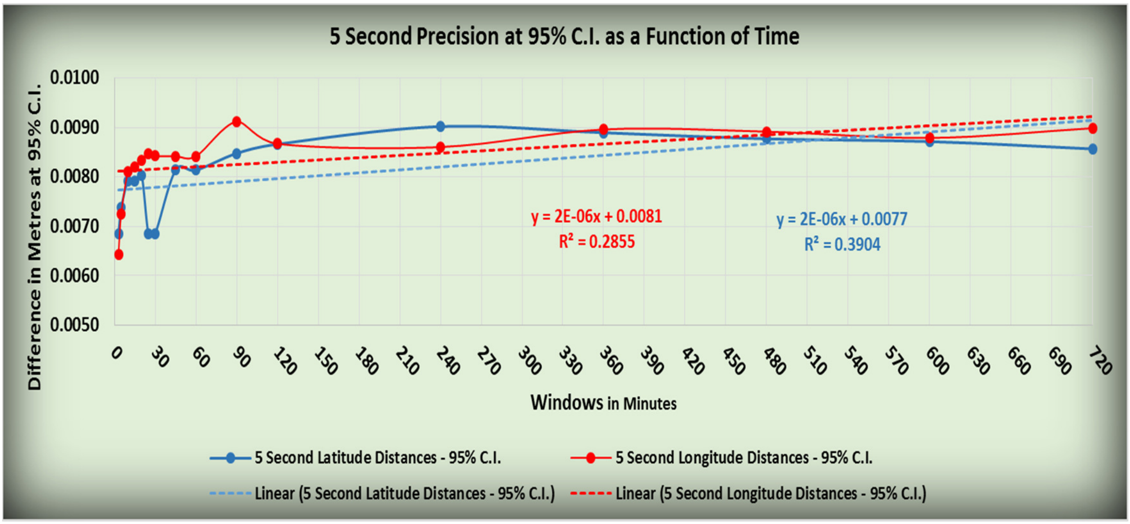


Figure 51: Pictorial of the 5 second averaged epoch precisions over increasing time windows at 95% C.I.

Examination of Figure 51 (above) and Table 7 (see below) reveals the latitude and longitude 95% C.I. only varies by 0.0017m and 0.0026m for latitude and longitude respectively between the shortest time windows of 3 minutes to 720 minutes.

The reader is directed to the R^2 values of the latitude and longitude, 0.3904 and 0.2855 respectively. These values are a determination of how closely the data conforms to a linear relationship. If the values were equal to one (1) then there would be a perfect fit between the data and the drawn line through it and if the values were equal to zero (0) then no correlation between the data and the line would exist. As seen in the 0.3904 and 0.2855 values, there is some correlation between the data and the line. The trend-lines are increasing suggesting that precision is decreasing as evidenced by the constant (2^{-6}) in front of the x variable. The latitude and longitude trend-lines are converging after crossing the 'Y' axis at 0.0077m and 0.0081m respectively.

In Figure 51, the latitude 95% C.I. improves by 0.0016m at the 25 and 30 minute windows and the longitude 95% C.I. decreases by 0.0007m at the 90 minute window.

Time Window	5 Second Latitude Distances - 95% C.I.	5 Second Longitude Distances - 95% C.I.
3	0.0069	0.0064
5	0.0074	0.0073
10	0.0079	0.0081
15	0.0079	0.0082
20	0.0080	0.0083
25	0.0069	0.0085
30	0.0069	0.0084
45	0.0081	0.0084
60	0.0081	0.0084
90	0.0085	0.0091
120	0.0087	0.0087
240	0.0090	0.0086
360	0.0089	0.0090
480	0.0088	0.0089
600	0.0087	0.0088
720	0.0086	0.0090

Table 7: Tabular Description of the 5 second dataset over increasing time windows at 95% C.I.

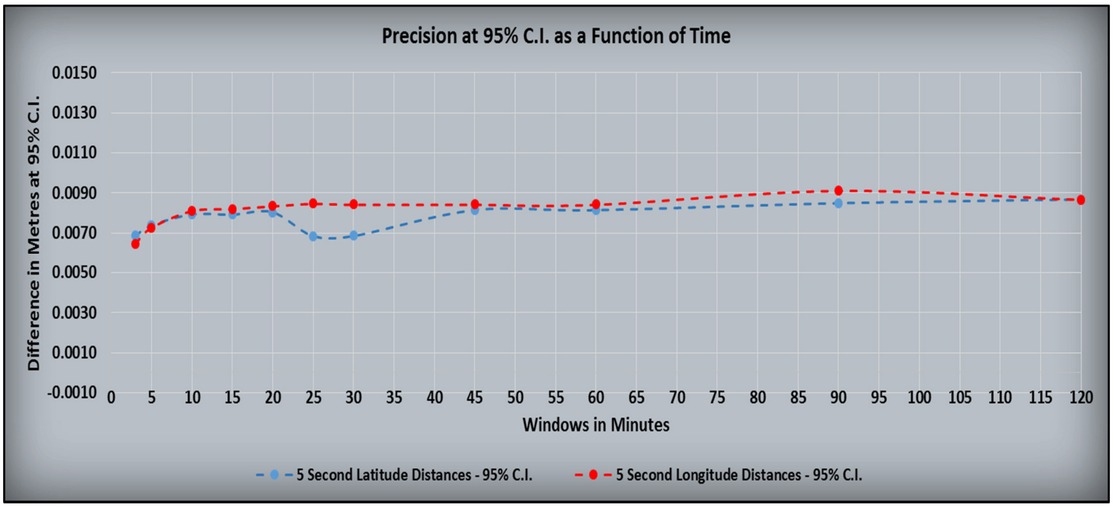


Figure 52: Re-graphed 5 Second dataset over increasing windows at 95% C.I.

Figure 52 is a re-graphed version of Figure 51 except its time windows cease at 120 minutes as opposed to 720 minutes as seen in Figure 51. This graph (Fig 52) does not exhibit the aggressiveness as the graph in Figure 51. As seen, the changes are relatively small.

The numerical range values of latitude and longitude at increasing windows, as seen in Table 8, also support the previous comment. Note the latitude and longitude 95% C.I. values at the 3 minute window and compare with the 30 minute window. Again they are small values but the data is tending to increase.

Range of 5 Second Dataset		
Window	Latitude	Longitude
3	0.048	0.051
5	0.050	0.054
10	0.048	0.060
15	0.057	0.060
20	0.048	0.059
25	0.048	0.072
30	0.048	0.063
45	0.052	0.063
60	0.052	0.060
90	0.056	0.081
120	0.051	0.067
240	0.053	0.062
360	0.056	0.063
480	0.052	0.062
600	0.053	0.055
720	0.050	0.064

Table 8: Range of 5 Second dataset at increasing windows

The recent introduction of new survey standards for the Queensland (refer Chapter 2, Section 2.3) survey profession does not support 5 second observation times. In fact, the legislation recommends a minimum of 1 minute observation time on the point and delay re-occupation by a minimum of 30 minutes. This research project does not support or recommend anything less than the recently introduced Queensland standards. The next natural process step is to proceed to the 1 minute observation time and apply the time interval windows used for the 5 epoch's average dataset which commenced at 3 minutes and proceeded incrementally through to 240 minutes. The 1 minute observation time has been recommended by previous researchers such Gibbings & Zahl (2014) Janssen & Haasdyk (2011b) and is also a recommendation in the Queensland CSR's.

4.4 Five Second Observation Time at the Thirty Minute Window

This section deals with the 5 second observation time and the minimum delay time window as recommended in the Queensland CSR's. The 5 second observation time is not recommended in this dissertation but it does set a subsidiary platform as we enter into the Queensland CSR's minimum recommendations of 1 minute observation time and the 30 minute wait time before re-observation window.

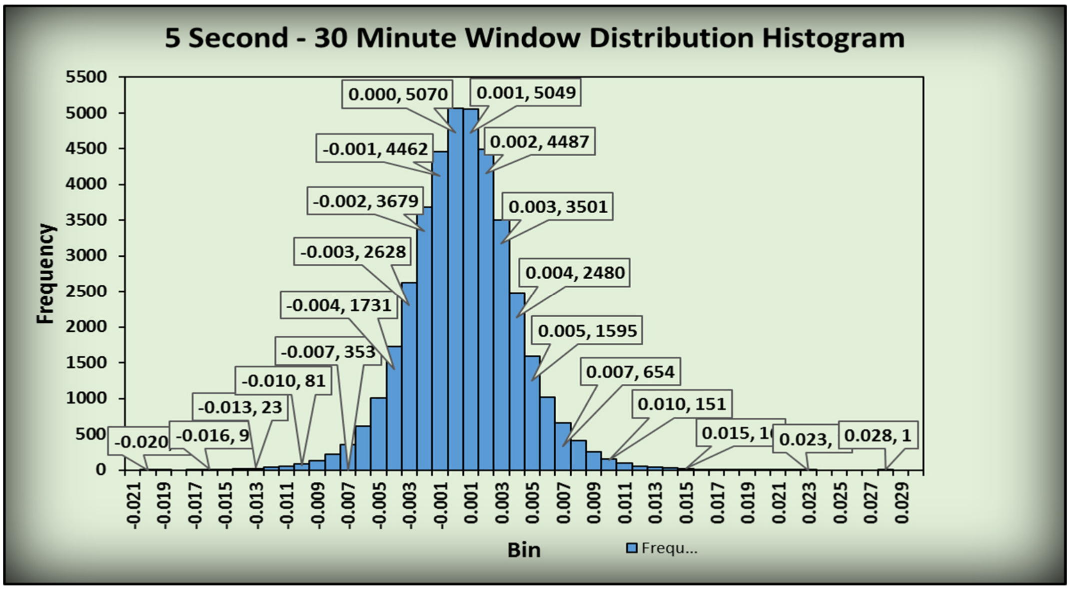


Figure 53: 5 Second/30 Minute Window Distribution Histogram

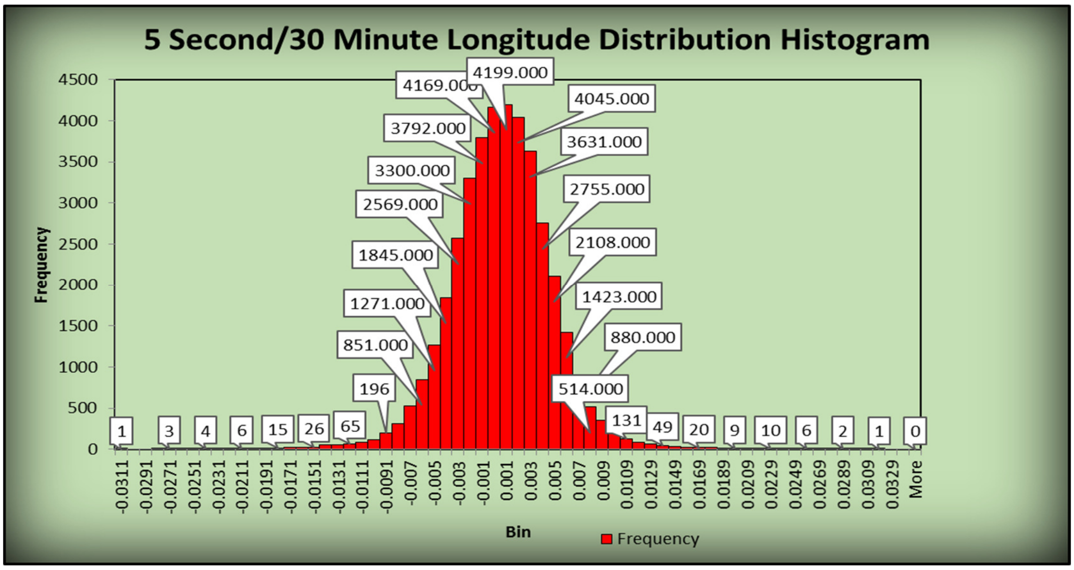


Figure 54: Longitude - 5 Second/30 Minute Window Distribution Histogram

Figures 53 and 54 demonstrate how close the latitude and longitude 5 second/30 minute datasets are to representing a perfect normal distribution. Note though, in Figures 55 and 56 the latitude and longitude are both very random in nature despite having the appearance of being normally distributed.

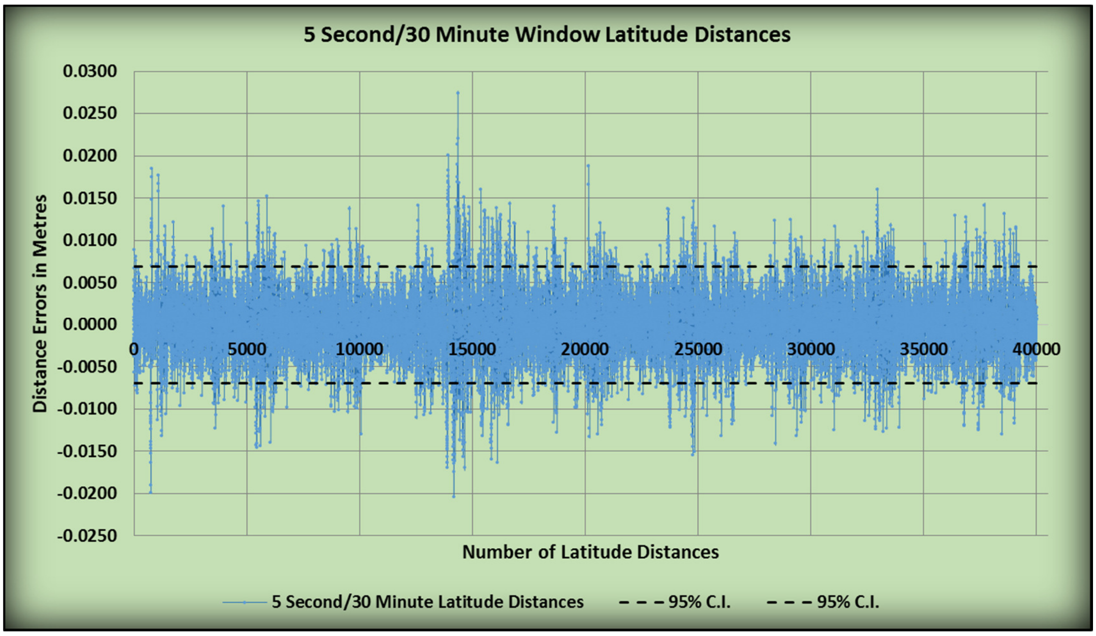


Figure 55: Latitude 5 Second/30 Minute Window Distances

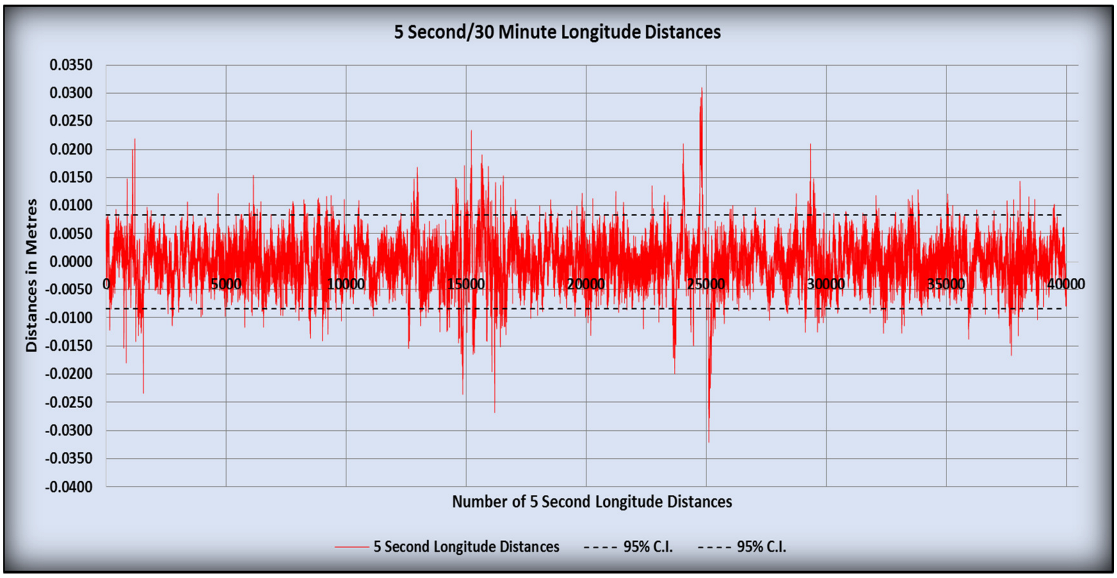


Figure 56: Longitude 5 Second/30 Minute Window Distances

5 Second/30 Minute Window		
Number of Distances	40009	
	Latitude	Longitude
Average	0.000001	0.000021
STDEV.S	± 0.0035	± 0.0043
95% C.I.	± 0.0069	±0.0084
3 Sigma	± 0.0090	± 0.0111
95th Percentile	0.0057	0.0064
2.5th Percentile	-0.0069	-0.0082
97.5th Percentile	0.0072	0.0081
Maximum	0.0274	0.031
Minimum	-0.0204	-0.0321

Table 9: 5 Second/30 Minute Window Statistics

Listed in Table 9 are the statistics associated with the latitude and longitude 5 second/30 minute window dataset.

4.5 Five Second/Ninety-fifth Percentiles

4.5.1 Five Second/Ninety-fifth (95th) Percentile Distances

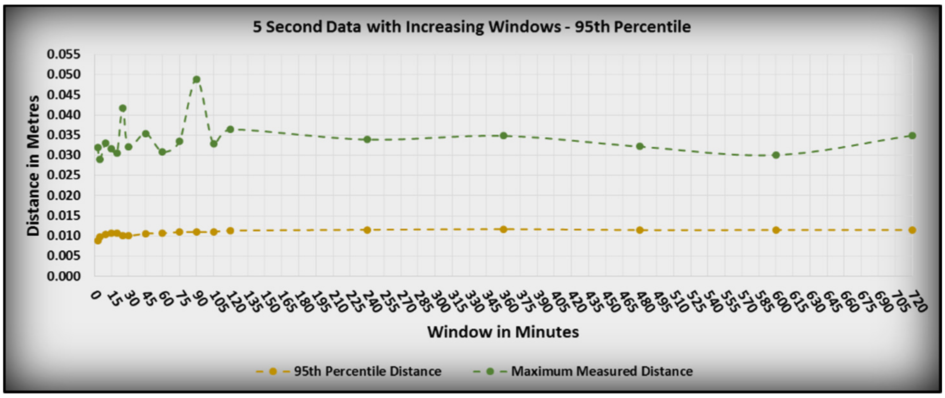


Figure 57: 95th Percentile - Absolute Measured Distance at Increasing Windows

Figure 57 demonstrates the maximum measured distance at increasing time windows of the entire 5 second dataset using the 95th percentile. Interestingly, none of the actual calculated measured distance values would comply with the Queensland CSR's. A major spike at around the 25th and 90th minute window is, as is other spikes, easily discernible in Figures 55 and 56. It is suggested the random nature of the errors associated with RTK causes such peaks and troughs. The tabular values are displayed in Table 10.

5 Second Dataset with increasing Windows - 95th Percentile		
Time Window	95th Percentile Distance	Maximum Measured Distance
3	0.0088	0.0320
5	0.0097	0.0290
10	0.0104	0.0330
15	0.0107	0.0316
20	0.0107	0.0305
25	0.0100	0.0418
30	0.0100	0.0321
45	0.0106	0.0354
60	0.0107	0.0309
75	0.0110	0.0335
90	0.0110	0.0489
105	0.0110	0.0328
120	0.0113	0.0364
240	0.0115	0.0339
360	0.0117	0.0348
480	0.0114	0.0322
600	0.0115	0.0301
720	0.0115	0.0349

Table 10: 5 Second/95th Percentile and Maximum Distances

4.5.2 Region at which 95th Percentile of Five Second Data Falls

Figure 58 represents the value at which 95% of data, at each window, falls below. Windows begin at 3 minutes and increase to 720 minutes. Figure 59 is a re-graphed Figure 58 with a reduction in the time windows from 720 minutes to 90 minutes. This has been completed to put the latitude spike seen around the 25-30 minute window into context.

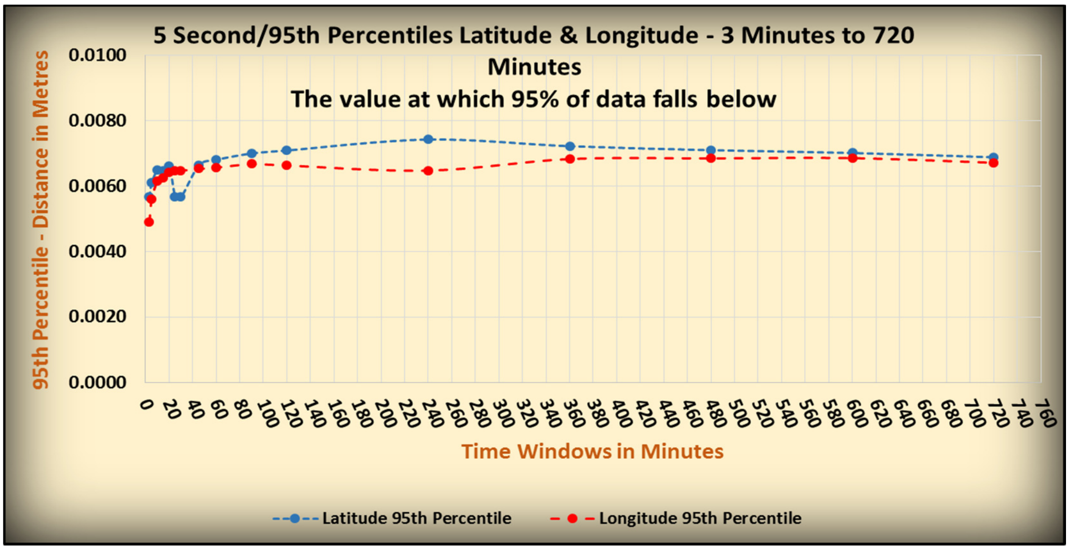


Figure 58: 95th Percentiles – the value at which 95% of data falls below

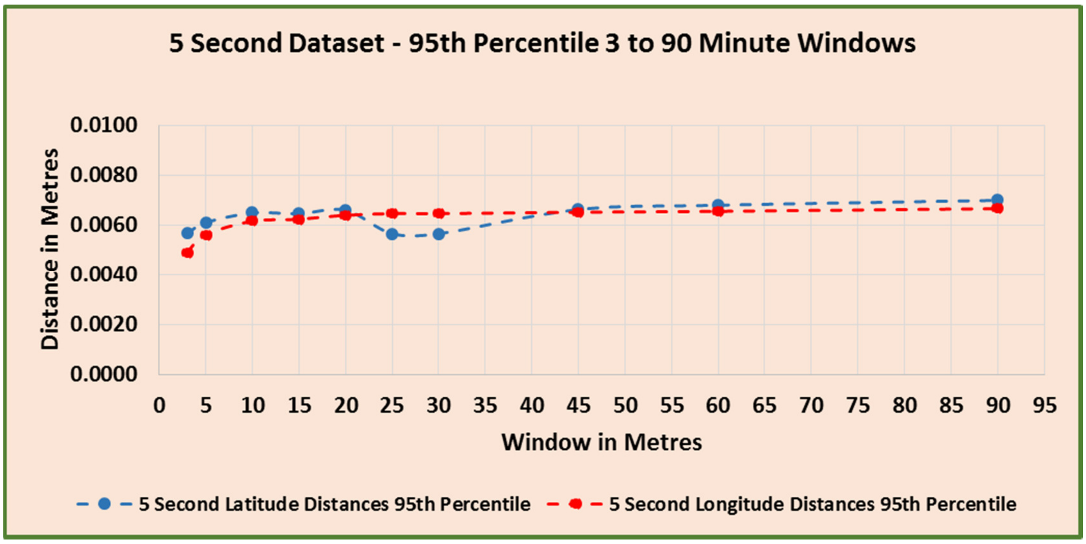


Figure 59: Re-graphed Figure 58 - 3 Minute to 90 Minute Windows

5 Second - 95th Percentiles		
Time Window	95th Percentile Latitude	95th Percentile Longitude
3	0.0057	0.0049
5	0.0061	0.0056
10	0.0065	0.0062
15	0.0065	0.0062
20	0.0066	0.0064
25	0.0057	0.0065
30	0.0057	0.0064
45	0.0066	0.0065
60	0.0068	0.0066
75	0.0069	0.0069
90	0.0070	0.0067
105	0.0073	0.0064
120	0.0071	0.0066
240	0.0074	0.0065
360	0.0072	0.0068
480	0.0071	0.0069
600	0.0070	0.0069
720	0.0069	0.0067

Table 11: 5 Second - 95th Percentiles at increasing Windows

Table 11 displays the 95th numerical values at increasing windows for the 5 second dataset. The increase in precision is noted around the 25-30 minute window for the latitude 95th percentile. The longitude did not experience the same improvement.

4.6 One Minute Observation Time Dataset

Figure 61 displays the 1 minute dataset point positions, commencing at the 3 minute and finishing at 720 minute window, at the 95% confidence interval. Table 13 provides the numerical display. Note the decrease in precision at the 90 minute window for the longitude distance.

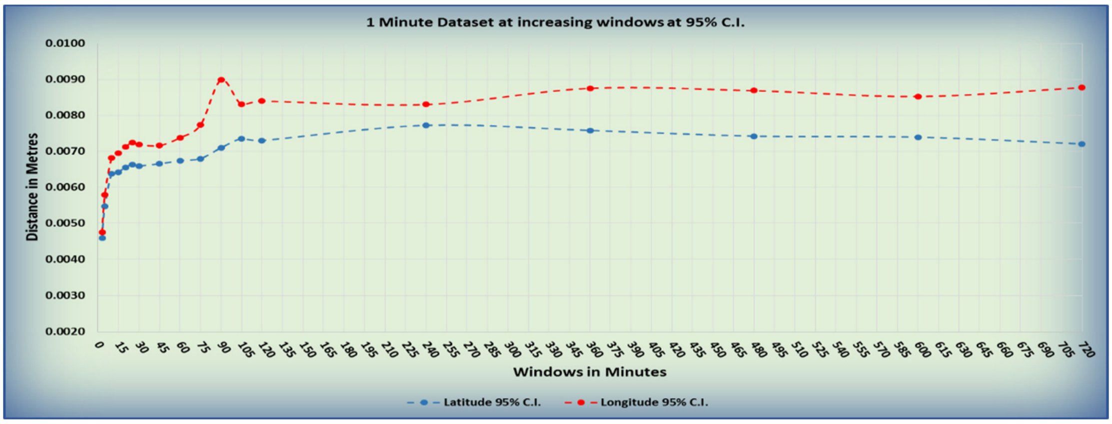


Figure 60: 1 Minute Dataset Point Positions at increasing Windows at 95% C.I.

1 Minute Dataset at increasing windows at 95% C.I.		
Window	Latitude 95% C.I.	Longitude 95% C.I.
3	0.0046	0.0047
5	0.0055	0.0058
10	0.0064	0.0068
15	0.0064	0.0070
20	0.0066	0.0071
25	0.0066	0.0073
30	0.0066	0.0072
45	0.0067	0.0072
60	0.0067	0.0074
75	0.0068	0.0077
90	0.0071	0.0090
105	0.0074	0.0083
120	0.0073	0.0084
240	0.0077	0.0083
360	0.0076	0.0088
480	0.0074	0.0087
600	0.0074	0.0085
720	0.0072	0.0088

Table 12: 1 Minute Dataset Point Positions at increasing Windows at 95% C.I.

4.6.1 One Minute – with Thirty Minute Window Point Positions at 95% C.I.

The 1 minute observation time and the thirty minute window produces 3334 point positions and is analysed and graphed (see Figure 62) for the purpose of making comparisons with the latest recommended Queensland cadastral survey standards (CSR). The CSR minimum standards are 1 minute observation time and a minimum of 30 minute delay time before re-observation of the same point. Note the descriptive statistics in Table 14 below.

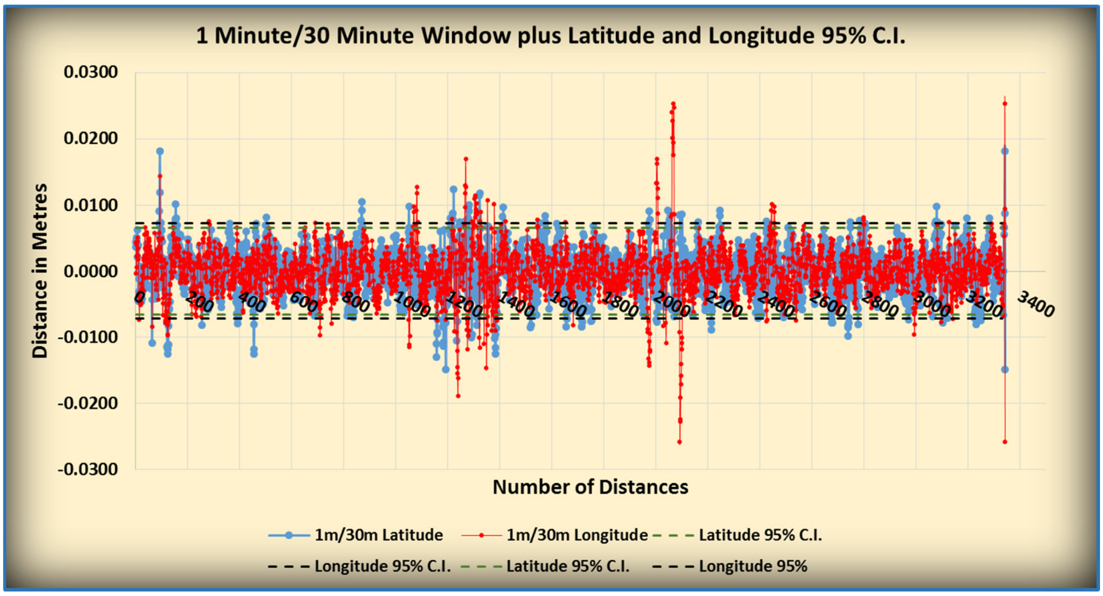


Figure 61: 1 Minute/30 Minute Window Latitude and Longitude Point Positions with the 95% Confidence Intervals

1 Minute/30 Minute Window Statistics		
	Latitude	Longitude
Average	0.0000	0.0000
2.5 Percentile	-0.0066	-0.0068
97.5 Percentile	0.0066	0.0066
95th Percentile	0.0055	0.0053
95% C.I.	0.0066	0.0072
99% C.I.	0.0087	0.0095
Maximum	0.0182	0.0253
Minimum	-0.0149	-0.0259

Table 13: 1 Minute/30 Minute Latitude and Longitude Point Positions with the 95% C.I.

4.6.2 One Minute Dataset – Maximum and the 95th Percentile Distances

The 95th percentile and maximum distances can be seen in Figure 63 and the numerical values in Table 15. Again, the spike around the 90 minute window is obvious. The maximum distances are a true representation of what the practitioner would achieve under the same conditions in a field environment. That is, if the practitioner could produce the same laboratory type conditions used for the research project.

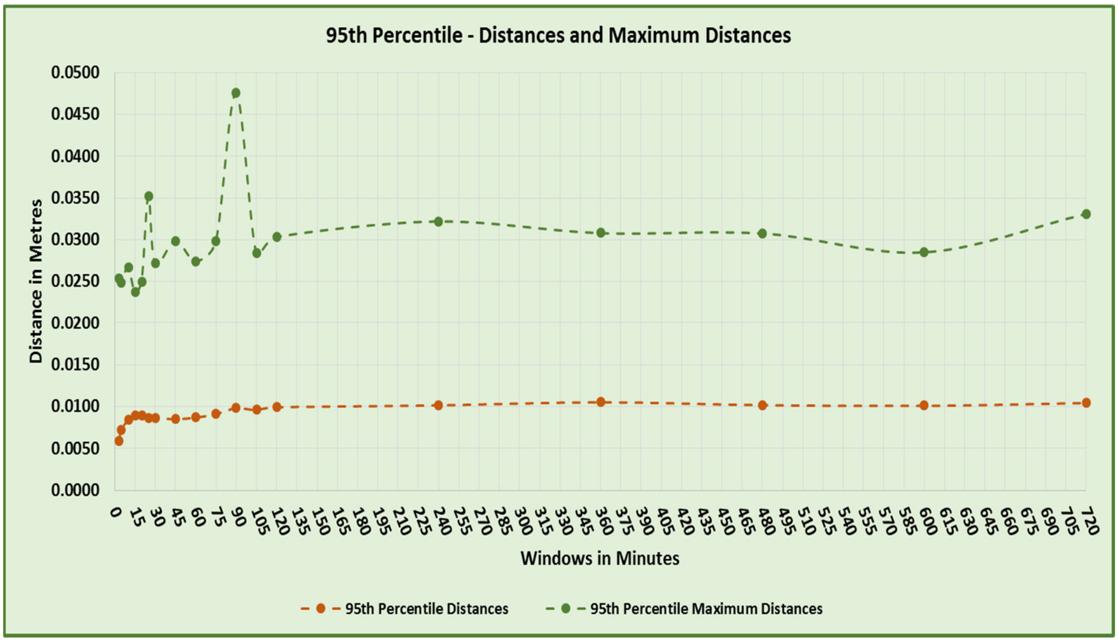


Figure 62: 95th Percentiles - Distances and Maximum Distances

1 Minute Dataset with increasing Windows - 95th Percentile Distances		
Window	95th Percentile Distances	95th Percentile Maximum Distances
3	0.0059	0.0254
5	0.0072	0.0249
10	0.0085	0.0267
15	0.0089	0.0237
20	0.0090	0.0250
25	0.0086	0.0352
30	0.0087	0.0272
45	0.0085	0.0299
60	0.0087	0.0274
75	0.0091	0.0298
90	0.0098	0.0475
105	0.0096	0.0284
120	0.0099	0.0303
240	0.0102	0.0322
360	0.0105	0.0308
480	0.0102	0.0308
600	0.0101	0.0285
720	0.0105	0.0331

Table 14: 1 Minute Dataset with increasing Windows - 95th Percentile Distances

4.6.3 Region at which the Ninety-fifth Percentile of One Minute Data Falls

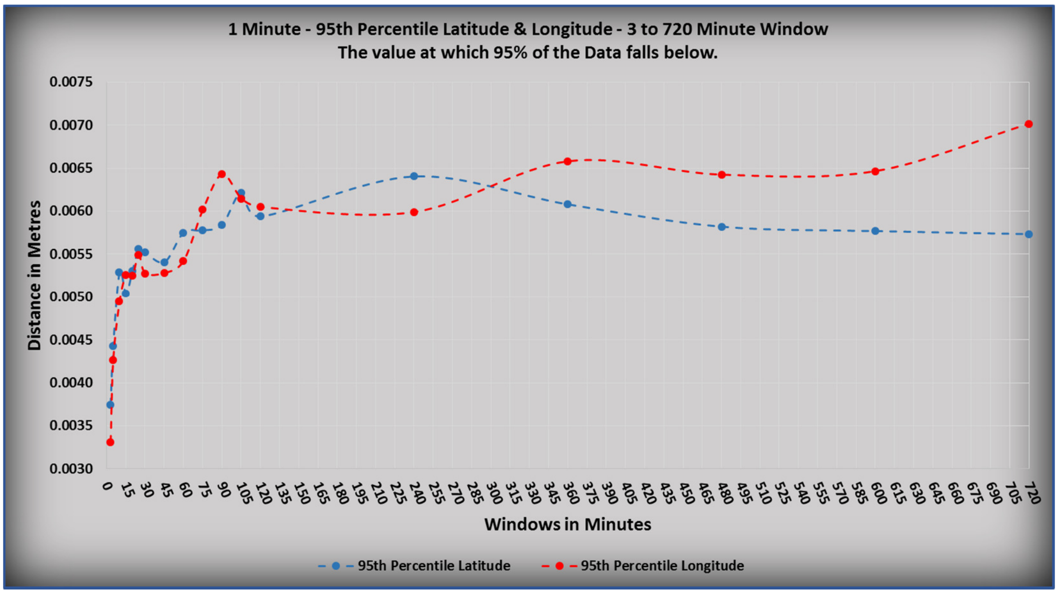


Figure 63: 1 Minute/95th Percentile Latitude & Longitude - 3m to 720m Windows

1 Minute – 95th Percentile Latitude & Longitude – 3 to 720 Minute Window		
Window	95th Percentile Latitude	95th Percentile Longitude
3	0.0037	0.0033
5	0.0044	0.0043
10	0.0053	0.0049
15	0.0050	0.0053
20	0.0053	0.0053
25	0.0056	0.0055
30	0.0055	0.0053
45	0.0054	0.0053
60	0.0058	0.0054
75	0.0058	0.0060
90	0.0058	0.0064
105	0.0062	0.0061
120	0.0059	0.0060
240	0.0064	0.0060
360	0.0061	0.0066
480	0.0058	0.0064
600	0.0058	0.0065
720	0.0057	0.0070

Table 15: 1 Minute - 95th Percentile Latitude & Longitude - 3m to 720m Windows

4.7 One Minute Observation Time with Increasing Windows at 95% Confidence Interval

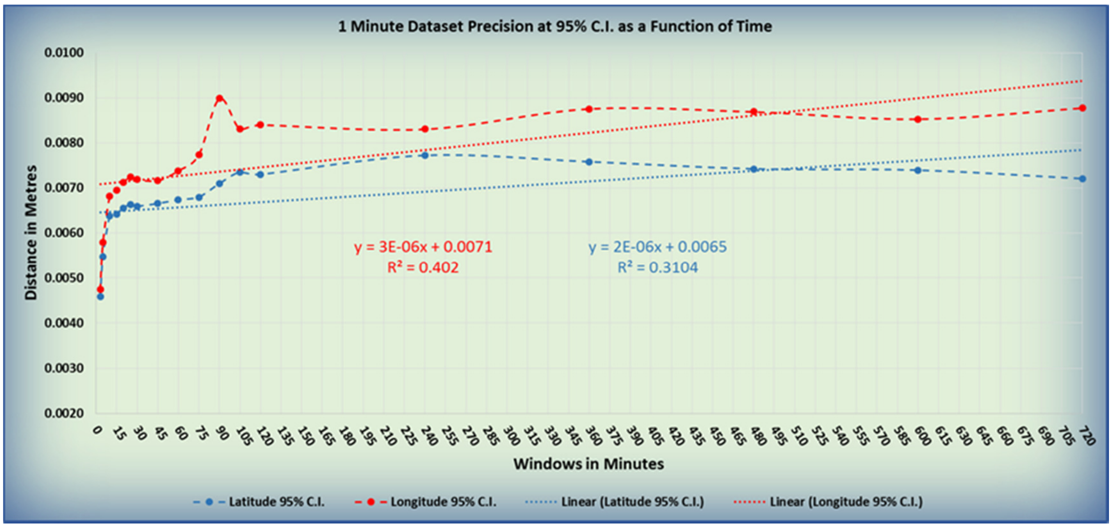


Figure 64: 1 Minute Dataset - Precision at 95% C.I. as a Function of Time

Figure 64 (above) and Table 16 (below) display the latitude and longitude 95% C.I. varies by 0.0026m and 0.0041m for latitude and longitude respectively between the shortest time windows of 3 minutes to 720 minutes.

The reader is directed to the R^2 values of the latitude and longitude, 0.3104 and 0.402 respectively. These values are a determination of how closely the data conforms to a linear relationship. If the values were equal to one (1) then there would be a perfect fit between the data and the drawn line through it and if the values were equal to zero (0) then no correlation between the data and the line would exist. As seen in the 0.3104 and 0.402 values, there is some small amount of correlation between the data and the line. The trend-lines are increasing suggesting that precision is decreasing as evidenced by the constant (2^{-6}) in front of the x variable but the longitude is increasing a little more quickly than the latitude trend-line. The latitude and longitude trend-lines are diverging after crossing the ‘Y’ axis at 0.0065m and 0.0071m respectively. This suggests the dataset (combined) will de-correlate further with time.

In Figure 64 and Table 16, the longitude 95% C.I. can be seen decreasing by 0.001m at the 90 minute window.

1 Minute Dataset at increasing windows at 95% C.I.		
Window	Latitude 95% C.I.	Longitude 95% C.I.
3	0.0046	0.0047
5	0.0055	0.0058
10	0.0064	0.0068
15	0.0064	0.0070
20	0.0066	0.0071
25	0.0066	0.0073
30	0.0066	0.0072
45	0.0067	0.0072
60	0.0067	0.0074
75	0.0068	0.0077
90	0.0071	0.0090
105	0.0074	0.0083
120	0.0073	0.0084
240	0.0077	0.0083
360	0.0076	0.0088
480	0.0074	0.0087
600	0.0074	0.0085
720	0.0072	0.0088

Table 16: 1 Minute Dataset at increasing Windows at 95% C.I.

4.8 Five Second and One Minute Observation over Increasing Windows at 95% Confidence Interval

Figure 57 graphically depicts the latitude and longitude 1 minute and 5 second observation times from the 3 minute window to the 720 minute at a 95% confidence interval.

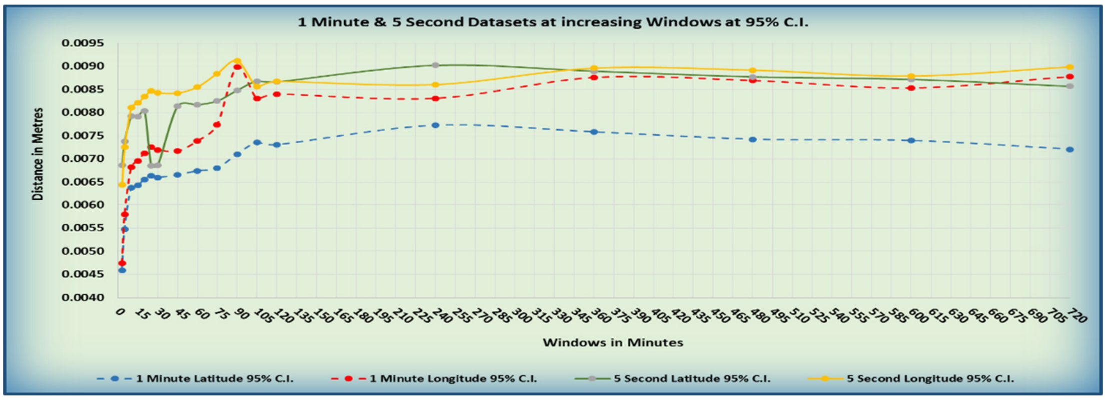


Figure 57: 5 Second & 1 Minute Observation Time Interval Window at 95% C.I.

Table 17 (below) provides a numerical table for the 5 seconds and 1 minute observation time on the point at increasing time intervals (3 minutes increasing to 240 minutes) at 95% C.I.

1 Minute & 5 Second Dataset at increasing windows at 95% C.I.				
Window	1 Minute Latitude 95% C.I.	1 Minute Longitude 95% C.I.	5 Second Latitude 95% C.I.	5 Second Longitude 95% C.I.
3	0.0046	0.0047	0.0069	0.0064
5	0.0055	0.0058	0.0074	0.0073
10	0.0064	0.0068	0.0079	0.0081
15	0.0064	0.0070	0.0079	0.0082
20	0.0066	0.0071	0.0080	0.0083
25	0.0066	0.0073	0.0069	0.0085
30	0.0066	0.0072	0.0069	0.0084
45	0.0067	0.0072	0.0081	0.0084
60	0.0067	0.0074	0.0082	0.0086
75	0.0068	0.0077	0.0082	0.0088
90	0.0071	0.0090	0.0085	0.0091
105	0.0074	0.0083	0.0087	0.0086
120	0.0073	0.0084	0.0087	0.0087
240	0.0077	0.0083	0.0090	0.0086
360	0.0076	0.0088	0.0089	0.0090
480	0.0074	0.0087	0.0088	0.0089
600	0.0074	0.0085	0.0087	0.0088
720	0.0072	0.0088	0.0086	0.0090

Table 17: 1 Minute & 5 Second Datasets at increasing windows at 95% C.I.

4.9 Summary

Chapter 4 saw the research data validated against previous notable researchers' and by mathematical methods. Listed below in dot point form is the data computations and statistical analysis performed and presented on the following datasets;

- Single epoch data analysis
- Single latitude epochs analysed and defined
- Single longitude epochs analysed and defined

Then progressing into the five second datasets as follows.

- Five second/three minute window dataset at 95% C.I. analysed
- Five second observation time with increasing windows at the 95% C.I.
- Five second observation time at the thirty minute window
- Five second/ninety-fifth percentiles
- Region under which 95th percentile of 5 second data falls
- The 95th percentile range for five second data

Then progressing into the 1 Minute Observation Time dataset as follows.

- One minute dataset distances at increasing windows at the 95% C.I.
- One minute observation time at the thirty minute time window
- Maximum and 95th percentile distances for the 1 minute dataset
- One minute observation time with increasing windows at the 95% C.I.
- A combination of the five second and one minute observation times over increasing windows at the 95% C.I.

Chapter Five will see the results compared with previous prominent researchers' results and comments to allow the reader to further build on the original platform. The reader is reminded the research data has been collected under laboratory type conditions.

CHAPTER 5

RESULTS and DISCUSSION

5.1 Introduction

Chapter Four saw the research data validated, analysed, graphed and presented in various formats using Microsoft Excel.

In this chapter, the results of those processed data will be presented and discussed. Through the processing strategy, mathematical model and the graphs produced for the accuracy and precision components for various observation times and time windows, an indication of what has been achieved and how these results compare with the Queensland CSR's.

To verify the results, it requires comparisons between these results and other notable researchers' results. It is acknowledged and noted that much of the previous research, although thorough, has a more academic content and context. This research dissertation tries to maintain a single focus, in terms of its content and context, and that is to remain at a level which the everyday practitioner can easily understand and relate to.

5.2 Discussion

The aim, which is to investigate the effect the time interval variations (windows) on a derived distance when using RTK, has been satisfied in Chapter Four. But only for when collecting data using the GPS and GLONASS satellite constellations and a single-base RTK system.

Has the research problem question been successfully answered? That is, does the time elapsed between observing the first point and the second point using RTK GNSS affect the accuracy and precision of the derived distance between the two points? I suggest it has been, and a solid evidence base will be provided in this chapter. With regards to the problem, this research is based on distances and not point position accuracy and precision. A research topic that appears to be new as little to no previous research data could be found. However, the author will endeavour to manipulate any relevant research into a format that comparisons can be drawn. The author would like to alert the reader to the fact that is not the most suitable approach and that, the results produced in this dissertation stand for themselves and, as a result of this, basically present themselves.

The data validation process will not be revisited in this chapter. In addition to this, the single epoch analysis will only be lightly discussed, simply because it has not undergone the considerable processing that the remaining data has been subjected to. The fact the single epoch data has not undergone the considerable processing also means it will not influence or be included in the final conclusions and recommendations.

5.3 Results

5.3.1 Single Epoch Data Analysis

The single epoch analysis did reveal there are no noticeable trends, behaviour or patterns between the latitude and longitude range, accuracies or precisions (Figure 40 and 41). This is to be expected given it is raw RTK data, although collected under laboratory type conditions.

The random nature, which is caused by the temporal errors associated with the broadcast signal sent by the space vehicles, is well evidenced in the graphs.

5.3.2 Single Latitude Epochs Defined

Figure 42 is the first graph to display the near normal distribution of the latitude data and Figure 43 provides the statistical analysis.

5.3.3 Single Longitude Epochs Defined

Figure 44, again, demonstrates how close the raw data is to a normal distribution. Figure 45 provides the point position descriptive statistical data. Table 5 evidences the afore-mentioned statement in regards to the normal distribution. The intention of the single epoch analysis was to reveal what trends, behaviours, positional point accuracies and precisions can be expected from raw RTK single-base system.

5.3.4 Five Second/Three Minute Window Point Positions at 95% Confidence Interval

The 5s/3m processing strategy produced 80666 calculated zero-distance point positions each expressed in its latitude and longitude components in metres. This equates to 40333 latitude and longitude distances.

Once processed the 95% C.I. for latitude and longitude achieved 0.0069m and 0.0064m (Figure 47). The reader should note the statistics highlighted in Table 6 and the random nature of the latitude and longitude point positions in Figures 47 and 48. Janssen, Haasdyk & McElroy's (2011c) comments regarding the effects of averaging and windowing are very obvious in this dataset. There is an improvement in the 95% C.I. of 0.0007m in latitude and 0.0013m in the longitude 95% C.I when compared to 95% C.I. of the single epochs of data for latitude and longitude, as seen in Figures 46 and 47.

Figures 49 and 50 (Latitude and Longitude histograms) does demonstrate how close they are to the Gaussian distribution. These accuracies are good and above expected values but they do not provide much toward achieving the answers to the main problem. However, the reader can build on the first established platform by visualising and understanding the trends, behaviours and patterns which, they themselves, interpret from the results to this stage.

5.3.5 Five Second Observation Time with Increasing Windows at the 95% Confidence Intervals

Figure 51 provides the first 'real' evidence for the successful determination of the research problem. Interestingly, the data suggests observing points, at each end of a line for which a distance is to be derived, close together in time produces better accuracy. This does not support previous research by Janssen and Haasdyk (2011b) who suggest there are benefits associated averaging observations over a window of 1-2 minutes and re-occupying points 10-30 minutes later. As seen in Table 7, the greater the time between (elapsed) the first and second observation the more the accuracy decreases. Presently, it is noted that the precision of RTK observations are not improving with either a longer observation or window time.

The latitude data, as seen in Figure 51, does fluctuate between the 25th and 30th minute and the longitude spikes at the 90 minute mark. The reader is reminded that these fluctuations are minor and not significant, in terms of value, and the practitioner could reasonably expect fluctuations such as this in their everyday survey work. To provide real-time context Figure 51 was re-graphed in Figure 5.2. From the 3 minute window both the latitude and longitude can be seen increasing quite quickly until flattening out around the 30 minute mark. As the dissertation progresses the shape of the graph from Figure 52 will be referred to an 'upside J' or mathematically would replicate the $\int (x) = \ln (x)$ graph. The results being displayed in Figure 51 and evidenced in a numerical format in Table 8 do not, at this stage, support previous researchers' (Edwards et al. 2010; Janssen, Grinter & Roberts 2011; Janssen & Haasdyk 2011b) recommendations to delay re-observation by a minimum of 30 minutes. Further to this, the latitude and longitude accuracy is trending upwards, albeit, slowly.

5.3.6 Five Second Observation Time at the Thirty Minute Window

Figures 53 and 54 demonstrate how closely the 5 second data represents a normal distribution histogram. Each graph in Figures 55 and 56 have the 95% C.I. overlaid to allow the reader to visually inspect any outliers and their values. Note these graphs represent derived distances computed by observing the point for 5 seconds and then, returning, 30 minutes later and re-observing again and then, subtracting the second observation from the first observation. Table 9 provides the statistics for the data.

It can be seen (Table 9) that the average/mean of the 5s/30m dataset is basically zero and the 68% C.I. is ± 0.0035m (latitude) and ± 0.0043m (longitude). Janssen & Haasdyk (2011b) achieved 10-20mm at 68% C.I. using the Network RTK system and quote 0.015 – 0.024m at 95th percentiles when using a single-base RTK system. Interestingly, the 95th percentiles of 0.0057m for latitude and 0.0064m for longitude are considerably more accurate the Janssen and Haasdyk's (2011b) results mentioned above.

The benefits of the USQ laboratory type conditions are being evidenced. The 95% C.I. of ± 0.0069m (latitude) and ± 0.0084m (longitude), as seen in Figures 55 and 56 also stress the accuracy of the data. Outliers are expressed in terms of 3σ and Table 9 stipulates these values as ± 0.0090m (latitude) and ± 0.0111m (longitude). On inspection of the graphs in Figures 55 and 56 it can be seen that there are a considerable number of distances that occur at and above the 3σ.

5.3.7 Five Second/95th Percentiles

Figure 57 displays the 95th percentile distance, as well as, the actual measured distance within the 5 second dataset. The 95th percentile was achieved by applying the following formula to achieve a distance $\sqrt{(x^2 + y^2)}$. Obviously, the 95th percentile represents the value at which 95% of the data will fall below. The Queensland CSR states all surveyed lines must have a vector accuracy of 10 millimetres + 50ppm.

The reader is reminder that the 5 second observation is not recommended anywhere within this document and is being used only to produce a baseline or platform.

5.4 One Minute Observation Time Dataset

5.4.1 One Minute Dataset Point Positions with increasing Windows at the 95% Confidence Interval

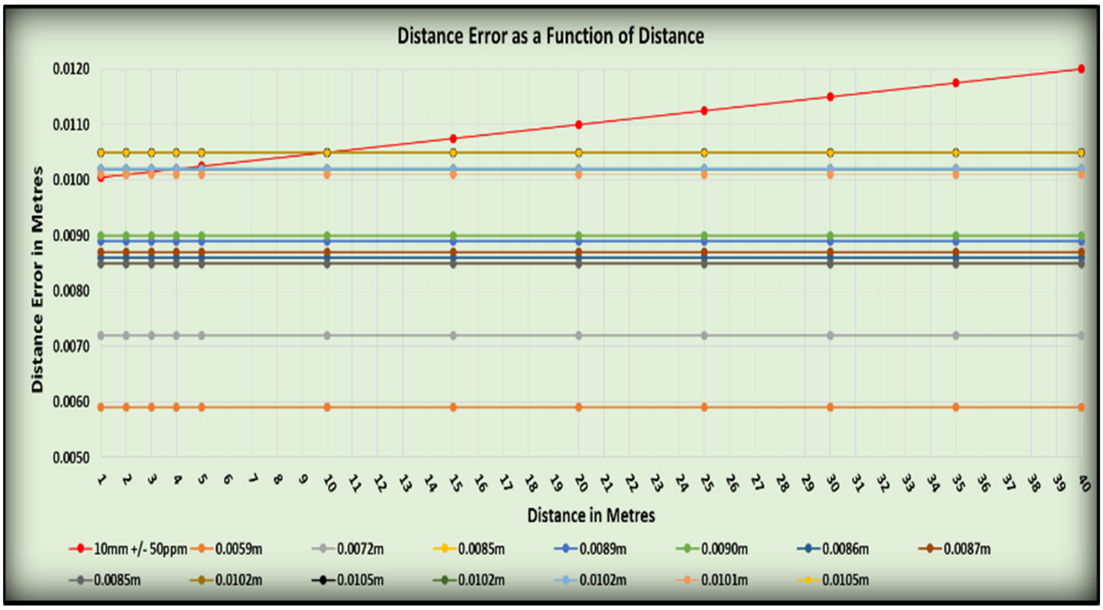


Figure 65: Distance Error as a Function of Time

1 Minute Dataset at increasing windows at 95% C.I.		
Window	Latitude 95% C.I.	Longitude 95% C.I.
3	0.0046	0.0047
5	0.0055	0.0058
10	0.0064	0.0068
15	0.0064	0.0070
20	0.0066	0.0071
25	0.0066	0.0073
30	0.0066	0.0072
45	0.0067	0.0072
60	0.0067	0.0074
75	0.0068	0.0077
90	0.0071	0.0090
105	0.0074	0.0083
120	0.0073	0.0084
240	0.0077	0.0083
360	0.0076	0.0088
480	0.0074	0.0087
600	0.0074	0.0085
720	0.0072	0.0088

Table 18: 1 Minute dataset at increasing windows at 95% C.I.

5.4.2 One Minute – with Thirty Minute Window Point Positions at 95% C.I.

The 1 minute observation and 30 minute window produces point positions only is the minimum recommendations stated in the Queensland CSR. The advantages this recommendation is well evidenced in Figure 67.

Inspecting Table 19 highlights that 3334 positions are produced, 95% of the point positions fall below 0.005m (latitude) and 0.0053m (longitude), the 95% C.I. is 0.0066m and 0.0072m respectively. As seen, outliers greater than 3σ do exists. However, 105 positions fall outside the 95% C.I. and when this occurs is random.

1 Minute/30 Minute Window Statistics		
3334	Latitude	Longitude
Average	0.0000	0.0000
2.5 Percentile	-0.0066	-0.0068
97.5 Percentile	0.0066	0.0066
95th Percentile	0.0055	0.0053
95% C.I.	0.0066	0.0072
99% C.I.	0.0087	0.0095
Maximum	0.0182	0.0253
Minimum	-0.0149	-0.0259

Table 19: 1 Minute/30 Minute Point Positions

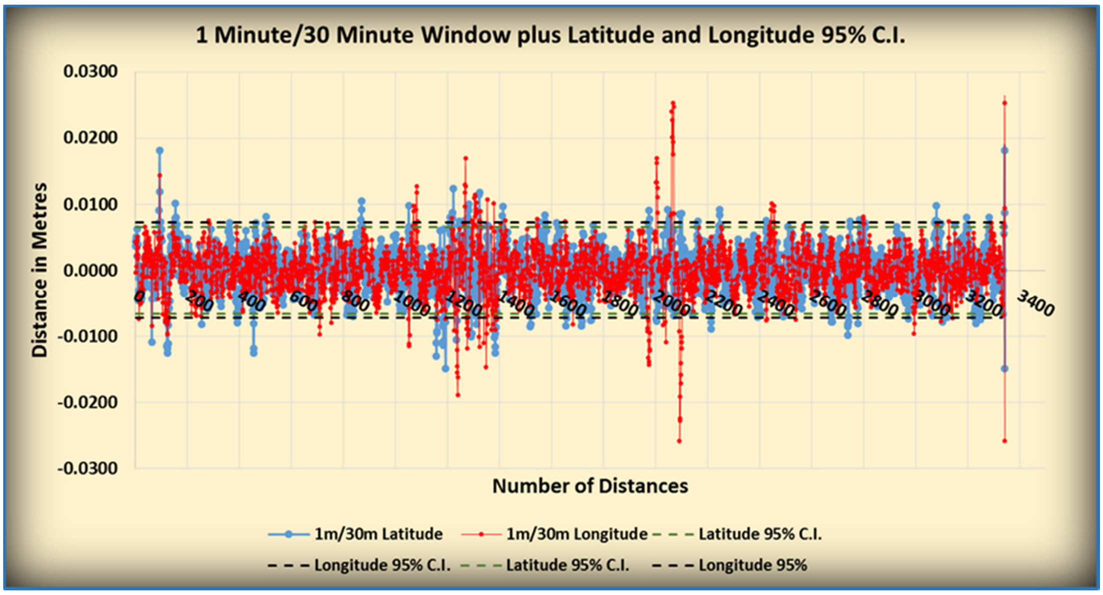


Figure 66: 1 minute/30 minute Point Positions

5.4.3 One Minute Dataset – Maximum and the 95th Percentile Distances

The maximum and 95th percentile distance are achieved by applying the Pythagorean Theorem ($\sqrt{(x^2 + y^2)}$ to the 95th percentile latitudes and longitudes and the maximum distance is computed by obtaining the maximum 1 minute latitude and longitude zero-distance baseline distances and applying the same rule.

Inspecting the 95th percentile distances first, it is seen that observing the same point quickly in time does improve accuracy remembering the 95th percentile means 95% of the distance falls within the stated values. There is 0.0028m difference between the 3rd and 30th minute window and 0.0018m between the 30th and 720 minute window. Working within the confines of the CSR vector accuracy (± 10mm + 50ppm) (will simply be referred to as vector accuracy from this point forward) and making comparisons with Figure 68 it is seen that none of these distances would satisfy the CSR requirements.

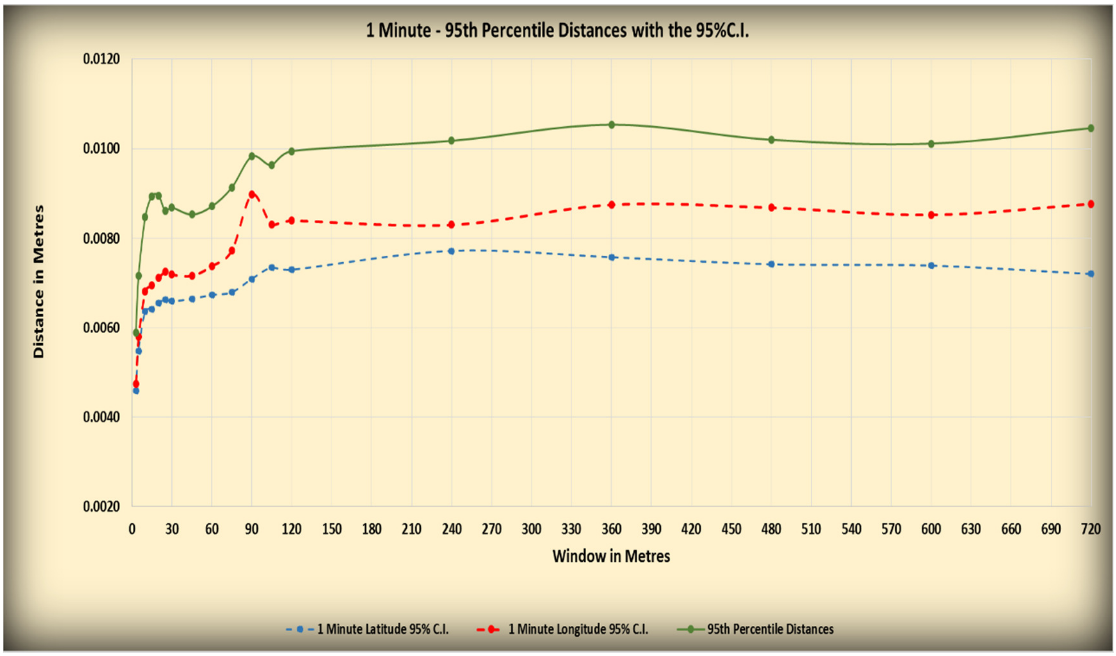


Figure 67: 1 Minute 95th Percentile Distances overlaid with the 95% C.I.

Figure 69 displays the 95th percentile and maximum distances overlain with the 95% C.I. The maximum distances shown are the distances outside the 95th percentile distances and, of course, are encountered by the practitioner in their everyday fieldwork. Quoting the 95th percentiles or 95% C.I. is important but focus should not be lost on the remaining percentiles and percentages.

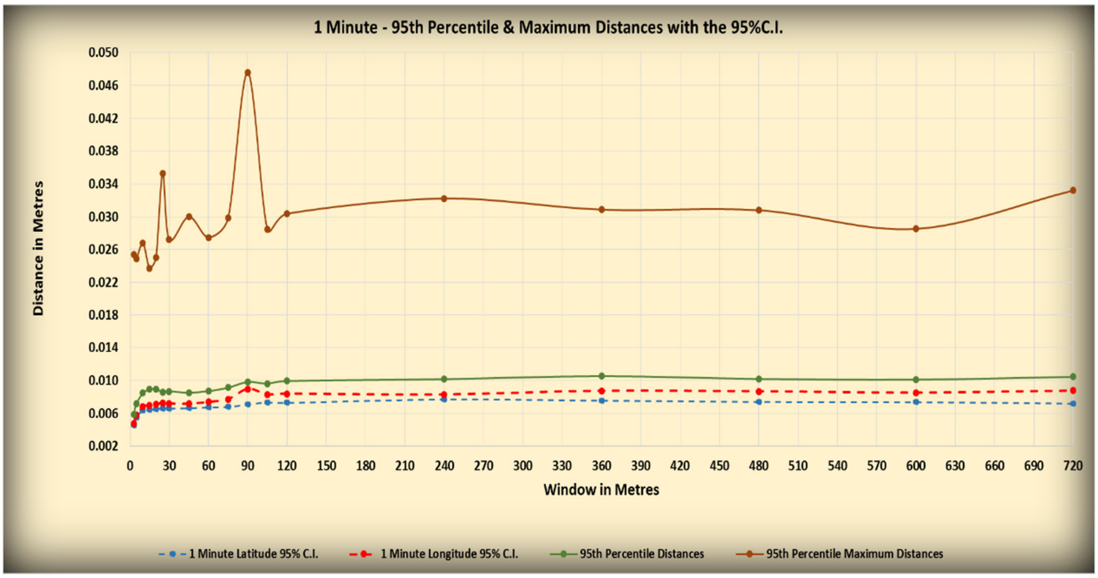


Figure 68: 1 Minute - 95th Percentile & Maximum Distances with the 95% C.I.

It is appropriate to quote other prominent researchers in this instance. Gibbings and Zahl (2014) analysed several thousand zero-distance baselines and found the 95th percentile with 30 second observations to be 23.7mm, and the 99th percentile as 28.9mm with a maximum standard deviation of 12.8mm. They noted that the 95th percentile for 3 second data was consistent with the 30mm at 95% achieved by Ong Kim Sun (2005).

Janssen and Haasdyk (2011) (see Figure 70 below) when using NRTK quote 90% of the horizontal positions have a precision of 10mm or better. When using single-base RTK over 12 km at the same location, only 60% of the positions fall within this precision. Similarly, inspecting Figure 70, 95% of the horizontal positions using NRTK have a precision of 13 mm or better. For single-base RTK at the same location, 95% of the positions have a precision of 15-24 mm for baselines ranging from 6 km to 22 km.

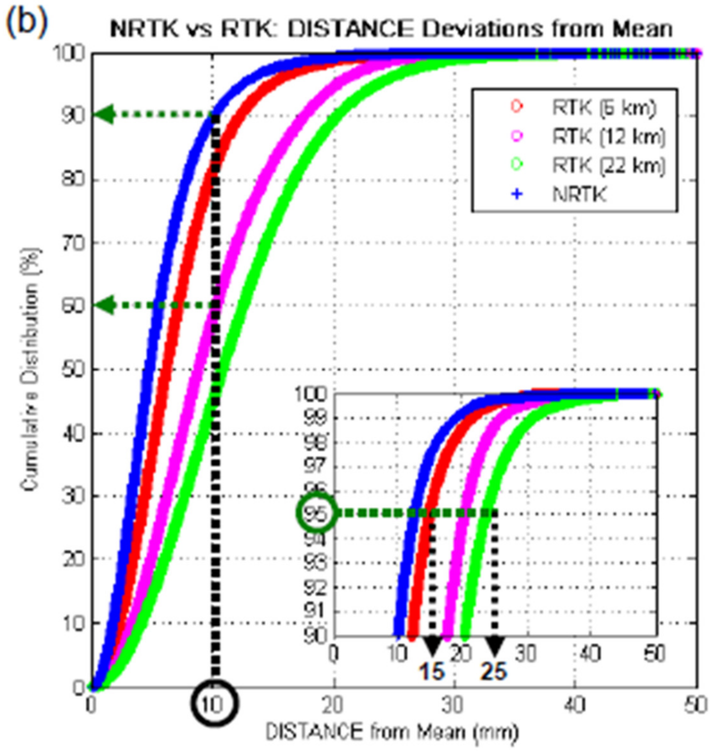


Figure 69: NRTK vs RTK: DISTANCE Deviations from the Mean
Source: (Janssen & Haasdyk 2011b)

5.4.4 One Minute Observation Time with Increasing Windows at 95% Confidence Interval

To analysis the 1 minute observation time with increasing windows the latitude and longitude distance error at the 95% C.I. overlain with the CSR vector accuracy needed to be graphed and it can be seen that the time window does have an effect on a derived cadastral distance. Note the decreasing accuracies, a rapid rise from the 3 minute window through to the 10 minute windows.

The advantages of the 1 minute observation time is well evidenced in Figure 71.   All of the 1 minute observation time distances from the 3rd minute through to the 720th window comply with the CSR vector accuracy standards. It is expected this to be the case in this environment and the fact, the latitude and longitude values are the 95% confidence interval values taken from the 1 minute dataset.

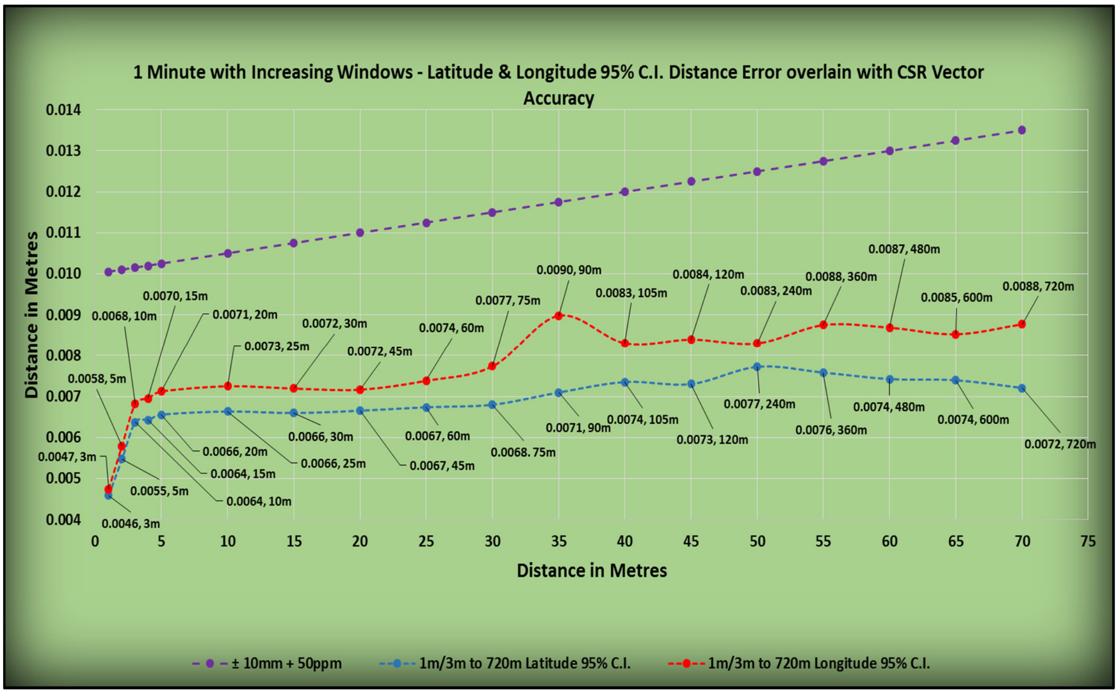


Figure 70: 1 Minute/Increasing Windows - Latitude and Longitude 95% C.I. Distance Error overlain with CSR Vector Accuracy

5.5 Five Second and One Minute Observations over increasing Windows at the 95% Confidence Interval

The 1 minute latitude and longitude distances over the increasing time windows at 95% C.I. are achieving better accuracies than the 5 second dataset as seen in Figure 72 and, again, noted in Table 20. The trends of both latitude and longitude in both the 1 minute and 5 second datasets provide evidence that windows do effect the accuracy of a derived cadastral distance. The trend clearly shows there are advantages in observing points as close as possible in relation to time.

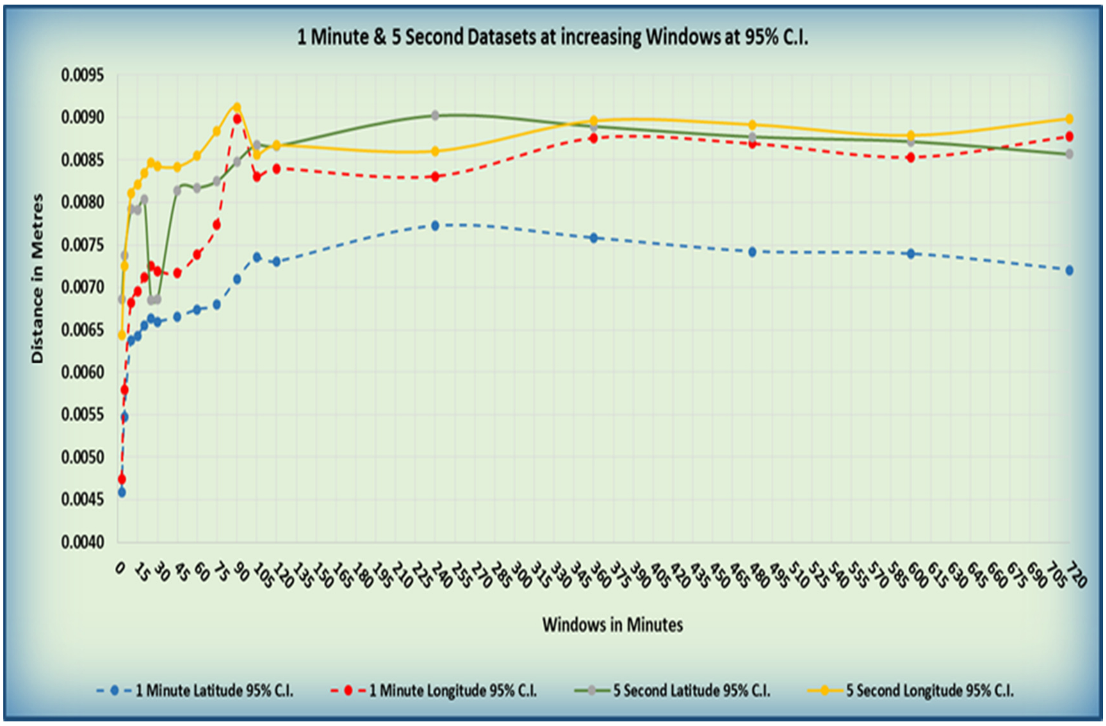


Figure 71: 1 Minute & 5 Second Datasets at increasing windows at 95% C.I.

1 Minute & 5 Second Dataset at increasing windows at 95% C.I.				
Window	1 Minute Latitude 95% C.I.	1 Minute Longitude 95% C.I.	5 Second Latitude 95% C.I.	5 Second Longitude 95% C.I.
3	0.0046	0.0047	0.0069	0.0064
5	0.0055	0.0058	0.0074	0.0073
10	0.0064	0.0068	0.0079	0.0081
15	0.0064	0.0070	0.0079	0.0082
20	0.0066	0.0071	0.0080	0.0083
25	0.0066	0.0073	0.0069	0.0085
30	0.0066	0.0072	0.0069	0.0084
45	0.0067	0.0072	0.0081	0.0084
60	0.0067	0.0074	0.0082	0.0086
75	0.0068	0.0077	0.0082	0.0088
90	0.0071	0.0090	0.0085	0.0091
105	0.0074	0.0083	0.0087	0.0086
120	0.0073	0.0084	0.0087	0.0087
240	0.0077	0.0083	0.0090	0.0086
360	0.0076	0.0088	0.0089	0.0090
480	0.0074	0.0087	0.0088	0.0089
600	0.0074	0.0085	0.0087	0.0088
720	0.0072	0.0088	0.0086	0.0090

Table 20: 1 Minute & 5 Second Dataset at increasing windows at 95% C.I.

5.6 Summary

The rigorous mathematical model and processing strategy used in this research project are functional, workable, accurate, and simple to replicate have provided definitive empirical results as previously seen. Firstly, the graphical results produced from this research data clearly mirror previous research conducted by notable researchers such as Gibbings, Janssen and Haasdyk, Odijk, Teunissen and Huisman. This provides evidence that the integrity of these results are without question and capable of scrutiny at the highest level.

The 1 minute observation time at increasing time windows produced the better results, in terms of accuracy, when compared to the 5 second observation time at the same increasing window times. All of the graphs and numerical tables highlight the effects to the accuracy of the latitude and longitude components as the time window between observations was increased. Increases in precision was observed but not to the extent of the accuracy component. Notable improvement in precision and accuracy was experienced in the 1 minute observation times and the 3 minute to 10 minute windows. The results support observing points in close succession.

Obviously, for reasons such as economic feasibility, generalised time constraints versus outcomes and economy to scale it would not be prudent to use the techniques and time windows utilised in this research project for everyday survey applications.

5.7 Implications

There has not been enough research completed to suggest the results achieved and presented in this dissertation to suggest there are any major implications. However, the advantages of observing points at either end of a line for which a cadastral distance must be derived when using a single-base RTK is clearly evident. It must be noted, that little improvement in precision was realised but certainly not comparatively when compared with accuracy.

The practitioner can observe either points of a line, in quick succession using the 1 minute observation time, for which a cadastral distance is to be derived when using RTK and comply with the CSR by not re-observing within the 30 minute window. Using this technique, the practitioner can achieve efficiencies with dues regard to the type of survey being undertaken and the environment which the survey is being conducted.

The accuracy and precision of RTK is well researched and, as a result of this, well documented. The results achieved in this research project has taken a step towards closing a technological gap. However, these results provide an opportunity for further research to aid in closing the gap further.

CHAPTER 6

CONCLUSION

6.1 Introduction

This research paper has investigated the effects of the time interval windows on an RTK derived distance. For the investigation of these effects a single-base RTK system at the University of Southern Queensland was utilised. This single laboratory type site and conditions proved exceptional as evidenced in the data and succeeding results.

6.2 Meeting the Aims and Objectives

The aim of this research is to investigate the effect of time interval windows on a derived distance when using RTK. It has achieved this successfully. The objective was to achieve an outcome for the aim. This also has also been achieved.

6.3 Findings and Recommendations

At the outset, it is important to note that these tests are not definitive even though they agree with previous research. They do, however, provide the first step in a series of needed steps for the research to reach a successful conclusion.

The research data was collected under laboratory type conditions. The mathematical model and processing strategy at least matches previous research standards and the results presented are above the standards of other notable researchers.

The findings in dot point form are listed below.

- No noticeable changes occur to the accuracy and precision of a derived distance at differing time interval windows when using a single-base RTK GNSS system using conventional GPS and GLONASS satellite constellations
- The data statistics are asymptotic and as expected do improve as more data is analysed
- The data, regardless of the mathematical model used, closely imitates a perfect normal distribution
- The 30 minute delay before re-observation of the same point is acknowledged and accepted.
- The mean, mode and median are not good descriptors of what the observational data is doing

6.4 Compliance to Standards

A secondary objective of this dissertation is to ascertain what affects the time interval windows on a derived RTK distance has on the current Queensland Cadastral Survey Requirements (Spatial Policy of Department of Natural Resources and Mines. *Cadastral Survey Requirements* 2015, Version 7.0). RTK, as a single survey instrument, will not satisfy the entirety of the cadastral standards but it has the capacity to be utilised, if used correctly, to satisfy certain components of it.

6.5 Observation Times

The five second observation time was chosen to develop a benchmark well below the one minute minimum observation benchmark recommended in the current CSR's. The author believes if an abnormality existed, it would have presented itself during the five second observation time analysis.

The one minute observation time was chosen because it is the minimum observation time on the point stipulated in the current Queensland CSR's. No other observation times were selected simply because longer times appear to be inefficient, considering the potential improvement in accuracy and precision.

6.6 Time Windows

The five second and one minute observation times were then exposed to increasing time windows commencing at zero minutes. Zero minute data are, simply, point positions and not residual distances. Previous research and the current Queensland CSR's recommend delaying re-observation of a point by a minimum of 30 minutes. Again, to establish a benchmark below regulatory recommendations, the time window commenced at 3 minutes. It has been assumed a practitioner may observe a point for the 5 second or 1 minute wait 3 minutes and then re-observe the same point for the predefined time.

When time windows and subsequent processing and mathematics is introduced residual distance errors are produced. These latitude and longitude residual distance errors are distances/departures from the arithmetic mean in either a north/south or east/west orientation. It is acknowledged that both magnitude and direction exist but the direction is not considered in this paper. In this instance, the zero-distance baseline method does not cater for direction. Again, it is acknowledged and noted in previous research by notable researchers' (Gibbings & Zahl 2014b, 2014a; Kim Sun & Gibbings 2005) that a direction error does exist.

The 95% confidence intervals of the residual distance errors are calculated and this result has been graphed at the increasing time windows. This mathematical model and processing strategy has clearly provided excellent graphical and accurate results with the trends, behaviour and patterns also clearly discernible.

6.7 Further Research

The rationale behind this research was to provide the audience and professionals with empirical usable results that can be related directly to real-life field applications. While this dissertation has satisfied its objectives, it has given rise for more research. The focus now needs to shift to eliminating the limitations associated with this research project.

This research project has several limitations as listed below;

- The data was collected using conventional GPS and GLONASS satellite constellations
- There are no setup errors because the antennae are on single poles, dyna-bolted to a concrete floor and held in place by adjustable steel stay wires
- The base station is a permanent CORS station and is securely held in position
- The site can comfortably be compared to a laboratory type site and conditions
- The research data is multipath free due to the laboratory type conditions
- Restricted access and site conditions allows for lengthy uninterrupted days of data collection under the above-mentioned conditions.

There is a need to eliminate these limitations because while ever they exist a complete definitive and empirical result cannot be achieved. These limitations cannot be achieved in the real-life field environment and the practitioner will, in their everyday fieldwork, experience field conditions without these limitations attached. This research project used conventional GPS and GLONASS with a single-base RTK system to collect the data and there are various other combinations of satellite constellations available for testing to analysis what trends and behaviours exist using the same mathematical model and processing strategy. Further testing is required using the Network RTK (NRTK) system and this system needs to be tested under a high multipath environment. The supplementary suggested research is listed below in dot point form.

- o Research using different satellite constellations
- o Conduct research under normal field conditions that include normal setup errors

- Use single-RTK GNSS Base Station, relocate the base and re-occupy the same points at different observation times and increasing time windows as used in this research project
- Conduct research using NRTK
- Subject all research to a high multipath environment

The results from this research project are definitive in themselves but only under the limitations associated with the project. Presently, it is extremely difficult for anyone, even the most skilled with considerable knowledge of geodetic surveying applications, to make judgement calls and professional decisions in their everyday work environment. Now that a platform has been set students, professional and scientific bodies need to take the initiative and continue research into this area, to achieve empirical results that aid in designing new techniques that merge into standards to aid and support the user and the professional practitioner in their survey work.

6.8 Recommendations

The aims of this paper were;

1. To investigate the effects of time interval variations when using RTK to derive a distance.

The problem statement was:

2. Does the time elapsed between observing the first point and second point to derived a distance between the two points, when using RTK, affect the accuracy and precision?

The only variable required to achieve a successful result, that needed isolating, was time. This was achieved and based on the results, the following recommendations are made in regards to the aim and problem statement.

- That a minimum of one minute length of observation time be adopted, as recommended in the Queensland CSR
- If and when possible observe the opposite end on the line, for which a derived distance is to be calculated, within the most efficient timeframe possible, giving due appreciate to the type of survey being undertaken and the environment which the survey is being conducted. This recommendation assumes the practitioner will, at some stage, re-observe the same points from a different Base Station.
- That a minimum of 30 minutes should elapse before re-observing the same point/s which the derived distance will be calculated. This recommendation carries the assurance that the minimum wait time of 30 minutes has elapsed to allow for constellation changes.

These recommendations are given based on the results from this research paper and should the practitioner deviate from the minimum survey standard requirements, they do so at their own risk and responsibility.

6.9 Conclusion and Project Closure

The aim of this research is to investigate the effect of time interval windows on a derived distance when using RTK. It has achieved this successfully. The objective was to achieve an outcome for the aim. This, also has also been achieved. To my knowledge, presently, there is no powerful tool, formulae or model that has the capacity to model the temporal errors associated with the RTK system to achieve a more accurate and precise coordinate position based on the true position of the point.

However, there are RTK techniques that have arisen from previous research (Edwards et al. 2010; Gibbings & Zahl 2014a; Janssen & Haasdyk 2011b) and as a consequence has been implemented into survey standards as they are revisited. Arguably, the Queensland survey standard of 10mm ± 50ppm at 95% C.I. is not stringent. But, it is a standard that relates directly to the National Measurement Act 1960 (Cwlth). Practitioners must be capable of verifying the distance measured and placed on a cadastral plan and as such, owe a duty of care to their clients and the general public. The client or general public has a defined right to rely on or even act on the information they have received from the surveyor. The surveyors' competency is not be questioned rather their obligations are being highlighted.

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APPENDIX A – Project Specifications

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING
ENG4111/4112 Research Project
PROJECT SPECIFICATION

For: **VINCENT BEIN**

Topic: Effect of Time Interval Variations on RTK Derived Distances.

Supervisor: Peter Gibbings

Enrolment: ENG4111 Semester 1 2015

ENG4112 Semester 2 2015

PROJECT AIM: This project will investigate if the time difference between RTK GNSS observations at each end of a line has any effect on accuracy and precision of the distance of the calculated line.

PROGRAMME: Issue A. 08/04/2015

1. Review of literature related to RTK GNSS, in particular, its relationship to cadastral surveying in Queensland. This will entail researching information on RTK GNSS point positioning, calculated distances between two observations and vector accuracy of observations.

2. The USQ CORS site will be used to collect an adequate amount of one (1) second epoch of data based on the zero length of line. This will allow both accuracy and precision to be assessed. A lack of familiarity of the procedures and methodologies adopted for the empirical determination of the results will motivate the end-user to place limitations on the results and some degree of caution should be exercised. The USQ CORS site has been chosen because it provides strength to the research because the site provides a process free of system errors which can potentially exist in the real-life surveying situation. Using this site under controlled conditions will provide validity and integrity to the results.

3. The data, collected as a NEMA string in GGA format (ddmm.mmmmm), will be imported into Microsoft Excel. Whilst in Excel the data will be reduced to latitude (north) and longitude (east) into decimal degrees and subtracted from the sample mean and then converted into vector accuracy or error in distance from the mean in millimetres. Once this is achieved it is envisage sixty (60) one second epochs will be averaged and the distanced calculated between each of these averaged results. Next, alternate results will be used to determine what the error or, distance in metres, is as the time between the observations increases. Following this process, the time intervals will be extended to included and calculations performed on three (3) minute, five (5) minute, one (1) hour, three (3) hours, six (6) hours and twelve hour intervals to produce the vector accuracy in millimetres for latitude and longitude. Twelve hours will ensure a full and complete change in satellite configuration.

4. The data will be graphed in Excel and critically analysed to produce empirical results. These are to ascertain what effect, if any, an increase of time between observations of the same point (zero-baseline) has on accuracy and precision and comparisons made to the current Queensland and the Surveyors Board of Queensland cadastral surveying standards and minimum guidelines and what the error might be on a cadastral plan.

AGREED:

STUDENT: Vincent Stanley Bein SUPERVISOR:

15/05/2015 ____ / ____ /