Proceedings of the 19th Association of Public Authority Surveyors Conference (APAS2014)
Pokolbin, New South Wales, Australia, 31 March – 2 April 2014

Looking at Cadastral GNSS from a New Angle

Wayne Fenwick
Trade & Investment, Crown Lands
Wayne.fenwick@lands.nsw.gov.au

ABSTRACT

Global Navigation Satellite System (GNSS) technology is increasingly utilised for cadastral surveying purposes. This paper presents a theoretical approach to the considerations that will affect the use of GNSS in cadastral surveying. Is it possible to measure an angle with GNSS? Can angles be derived by GNSS? Can a GNSS bearing be considered? What are the theoretical limitations of the current technology in terms of the Surveying and Spatial Information Regulation 2012? There should be an appreciation of the acceptable limits set out in the Regulation not limited to distance, but including angular tolerance and misclose tolerance. How would this translate to measurements taken by GNSS? Once this is understood, it may be possible to predict a minimum point separation for GNSS-observed points to comply with the Surveying and Spatial Information Regulation 2012. While this theory is useful, the proof is in the practical tests and the reality of observations. Two test methods are outlined to determine if the presented theory is sound.

KEYWORDS: *Cadastral surveying, GNSS, Surveying & Spatial Information Regulation 2012.*

1 INTRODUCTION

Global Navigation Satellite System (GNSS) technology has been used in surveying for the best part of 20 years. Many studies have been undertaken regarding repeatability of observations, the use for geodetic surveys and have tried to relate them to the Surveying and Spatial Information Regulation 2012 (SSIR 2012) or its predecessors (e.g. NSW Legislation, 2014a-d). These studies have mostly concentrated on the distance aspect of the SSIR 2012 and have not considered in depth the angular or misclose components that are also required to be met for cadastral surveys. Before studying the theoretical suitability of GNSS, a discussion needs to take place regarding what can be measured with GNSS.

As stated above most studies relate GNSS to distance measurement, yet in the process of obtaining the required data to determine a distance, is more information available? Can GNSS measure angles? Can angles be derived from GNSS observations? Or is it possible to consider a bearing from GNSS observations? After these questions have been considered, the standards set by SSIR 2012 need to be interpreted.

What is the purpose of the SSIR 2012 and its predecessors in relation to measurements? The SSIR 2012 clearly states the angular accuracy or angular misclose requirement of a survey. However, this is in terms of the number of traverse stations in the survey. Does this value also relate to any angle for a radiation from a traverse station? In GNSS terms, what is an acceptable error ellipse for a radiated point to comply with the SSIR 2012?

Now that the terms of reference have been identified, the theoretical suitability of GNSS for cadastral surveys can be considered. How does the current GNSS technology of 2014 measure in relation to the SSIR 2012? What methods of survey are suitable and how does point density affect the outcome? With all this theoretical knowledge, how does it compare in the real world? Two test methods have been adopted to validate the results of the theory presented in this paper.

While this paper seems to raise more questions than it supplies answers, the intention is to promote discussion on the uses of GNSS and investigate how the technology of GNSS can be integrated into cadastral surveying and to link it to the conventional measurement standards that have been prescribed by regulation.

2 ASSUMPTIONS

This paper is written with several assumptions that have been made. Best practice survey methods are observed to obtain the GNSS observations. All error ellipses are shown as radius (in circle terms) or half-major axis values. To appreciate the size of the total error tolerance, this value should be doubled, i.e. 3 mm sounds rather tight but 6 mm is about the size of a clout and is very realistic.

3 DISCUSSION OF ANGLES AND BEARINGS

Is there any difference between two end points of a traditional traverse, A & B, with the resultant closing line as a bearing and distance between the two points, as opposed to the same two points simultaneously measured by GNSS with the resultant line shown as a bearing and distance between points A & B? Is there any difference between two traditionally radiated points C & D, with a calculated line between them shown as a bearing and distance, as opposed to two GNSS points C & D with a line shown as a bearing and distance? Most people are comfortable with both concepts, i.e. measuring lines and derived lines with GNSS.

Now consider an angle. There are three points A, B & C, and with a theodolite set at B it is possible to measure the angle B. Is it also possible to measure the angle B with three GNSS receivers observing simultaneously? GNSS works for a line so why not an angle? Likewise, for three points C, D & E, traditionally radiated, an angle can be derived or calculated. However, is it reasonable to calculate the angle from three points measured with GNSS?

Is there a significant difference between measured and calculated angles and distances? How many cadastral surveys set up on a corner peg and read the angle between the streets or along the side boundary? Every cadastral surveyor radiates corner pegs and Reference Marks (RMs), and calculates the angle from the calculated definition of the streets. It is not practical excluding a green field subdivision to measure the angle as obstructions most often prevent direct measurement.

At the most basic level, a line is defined by two points and an angle is defined by three points. What is the common link between lines and angles? They are both defined by points regardless of where the points come from. In a cadastral surveying context that means the points could be a traverse station, a radiated point or a GNSS point. There is always an amount of contention about which method is more accurate but this will be discussed later.

The message to take from this discussion is that it is possible to determine an angle with GNSS. Many users of GNSS do just that but how many consider the accuracy of the results?

What about a bearing from two GNSS points? Consider a compass, within the framework of the magnetic field, a compass will provide a bearing based on the local magnetic field. The user places faith in the field and believes the field uniformly points north. History has shown this is not the case, however compasses are still used as a means of navigation and Deposited Plans have been based on magnetic north for many years. Regardless of the accuracy, a compass provides a bearing from one point to another point at some undetermined distance away. From the above discussion, it has been shown that two points define a line and therefore it is reasonable to conclude a line within a framework is defined as a bearing. GNSS works within a mathematical framework and can provide two points at a known distance apart, hence providing a line and therefore a bearing based on the mathematical framework.

On a less philosophical aspect, Surveyor General's Direction No. 9: GNSS for Cadastral Surveys (SG9 – LPI, 2013) includes several definitions about GNSS measurements. These seem to be limited to lines, however from the above they can equally be applied to angles. SG9 states "*A GNSS measurement will be deemed as a direct measurement if it is determined from a single GNSS vector which was observed simultaneously at each end of the line*." Vectors by definition have both direction and magnitude. If it is reasonable to measure two vectors simultaneously, therefore an angle has been measured by default. This requires three GNSS receivers, however the principle is sound.

SG9 states "*A GNSS measurement will be deemed as a derived measurement, if it is determined indirectly by non-simultaneous GNSS observations at each end of the line*." If it is reasonable to derive a line from non-simultaneous GNSS observations, then it should be reasonable to derive an angle from non-simultaneous GNSS observations.

SG9 further states "*GNSS observations produce either three-dimensional absolute position measurements or relative three-dimensional vector measurements between positions. These measurements must be converted to two-dimensional (grid bearing and horizontal ground distance) measurements for inclusion on the survey plan*." This statement includes the term 'bearing' which seems to validate the argument that it is possible to measure and derive angles and bearings from GNSS observations. However, before it is possible to compare angles measured by GNSS and by theodolite or total station, it is necessary to investigate how angles are measured by a theodolite.

A theodolite is used to measure an angle by two pointings, i.e. one at the reference object and the other to the foresight. Therefore there are two error ellipses to consider in any one angle. However, there is only one error ellipse on the foresight and only one error ellipse on any radiation. The SSIR 2012 has tolerances for angular misclose which will be discussed in detail shortly. By what method is it possible to convert the SSIR 2012 tolerances to a suitable tolerance for radiations?

Figure 1 shows how the allowable error is distributed in an angle when measured with a theodolite. Angle ABC has an allowable error of *E*. *E* shows the allowable error spread over the whole angle (e.g. in a triangle, each angle is allowed to have 9 seconds of error – see Table 3 for 2012), however this is not the case. The allowable error only occurs at the targets. Half this error is from the target at A and half from the target at C. Half the allowable error is noted as *E/2*. In order to determine the allowable errors in millimetres, the equations stated in

Figure 1 are used, i.e. MAa and MAc for A and C respectively. The allowable errors stated in the SSIR 2012 are relative errors; these should be considered to be a combination of the errors at both ends of the line.

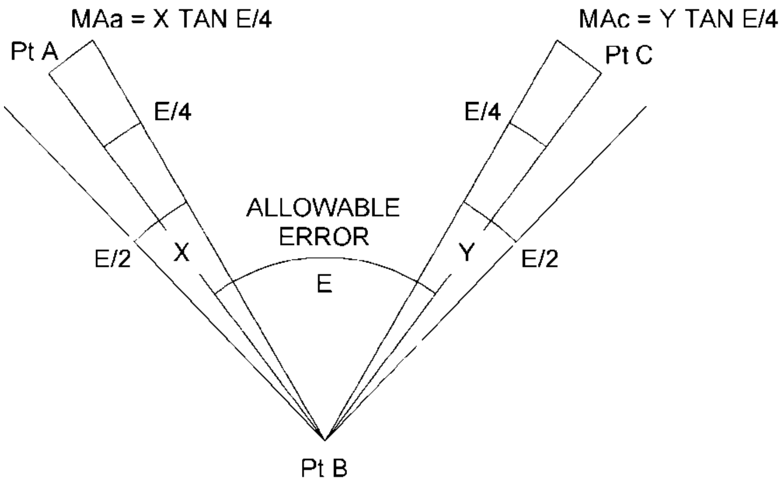

Figure 1: Allowable tolerance for angle measured by theodolite.

4 REGULATIONS AND STANDARDS

4.1 Distance Requirements

SG9 states "*Cadastral survey length accuracy (10 mm + 50 ppm) closely equates to the Class C category. Table 1 below shows the relationship between the class of surveys with relation to point error and relative errors over a line. This means that if the GNSS equipment/method being used has a stated point accuracy of no better than 0.020 m (without regard for setup errors and site considerations) to attain class C the minimum length measured should be 400 m. Using GNSS equipment under 400 m for cadastral purposes would require proof of point error accuracy through validation*."

Table 1: Class derived from station density and point error ellipse size (at 95%). The relative error ellipse size used in the determination of class is stated in parentheses (Dickson, 2012; LPI, 2013).

Station Density (km) \ Point and (Relative) Error Ellipse	0.010 m (0.014 m)	0.020 m (0.028m)	0.030 m (0.042m)	0.040 m (0.056m)	0.050 m (0.070 m)	0.060 m (0.084m)	0.070 m (0.096 m)
0.1	C	D	E	E	–	–	–
0.2	C	D	E	E	E	–	–
0.4	B	C	D	D	E	E	E
0.6	B	C	C	D	D	E	E
0.8	A	B	C	C	D	D	D
1	A	B	B	C	C	D	D
2	A	A	B	B	C	C	C
5	2A	2A	A	A	A	B	B
10	3A	2A	2A	2A	A	A	A

The SSIR 2012 has many components that must be met before a survey can be deemed to comply. From a GNSS perspective, distance is well understood but the angular component and misclose requirements are less studied and not so well understood. SSIR 2012 clause 25 states that all measurements must be made to ± (10 mm + 50 ppm) at a 95% confidence. This has been tested on many occasions and is well understood in terms of GNSS ability.

It is interesting to note from Table 2 that while the minimum measurement has not changed, i.e. in 1933 it was possible to measure to a 1/16 of an inch (1.5 mm) and in 2012 a high-accuracy Electronic Distance Measurement (EDM) instrument is deemed to deliver ± (2 mm + 2 ppm), yet the required accuracy in 2012 over a 30 m line is four (4) times as high as it was in 1933. In contrast, for any line over 1,000 m the expected tolerance is less than before, but not to the same extent, even though it is much easier to measure long lines with modern equipment.

Table 2: Allowable distance errors from regulations by years (all values in metres).

	1:12,000	6mm+30ppm	20mm+30ppm	10mm+50ppm
Dist	1933	1996 / 2001	2006	2012
10	0.001	0.006	0.020	0.011
30	0.003	0.007	0.021	0.012
50	0.004	0.008	0.022	0.013
100	0.008	0.009	0.023	0.015
250	0.021	0.014	0.028	0.023
500	0.042	0.021	0.035	0.035
750	0.063	0.029	0.043	0.048
1,000	0.083	0.036	0.050	0.060
2,000	0.167	0.066	0.080	0.110

4.2 Angular Requirements

The angular requirements of SSIR 2012 clause 24 are set out in terms of a traverse misclose, i.e. the number of stations determines the acceptable angular misclose. While this works well with conventional methods for the traverse, it is not able to be applied to GNSS as the methodology of measurement is completely different.

Using Figure 1, it is possible to covert the allowable error into a linear distance error ellipse. For example, consider the SSIR 2012 value for a triangle in Table 3. The total allowable angular misclose of 27 seconds divided by the number of angles equals 9 seconds per angle. Using the equation from Figure 1, i.e. *MA* = *Dist* tan(9”/4), gives the results shown in Table 4.

Table 3: Angle misclose limits in seconds, set by regulations by years.

	30+20√n	per angle	20+10√n	per angle	10+10√n	per angle
No Stations	1933 / 1996	Sec	2001 / 2006	Sec	2012	Sec
3	65	22	37	12	27	9
5	75	15	42	8	32	6
10	93	9	52	5	42	4
15	107	7	59	4	49	3
20	119	6	65	3	55	3

Table 4: Angle tolerance for 9 seconds of arc expressed as metres.

Dist	1933	2001	2012
10	0.000	0.000	0.000
30	0.001	0.000	0.000
50	0.001	0.001	0.001
100	0.003	0.001	0.001
250	0.007	0.004	0.003
500	0.013	0.007	0.005
750	0.020	0.011	0.008
1,000	0.026	0.015	0.011
2,000	0.052	0.029	0.022

4.3 Requirements for Radiations

While SSIR 2012 states angular measurement tolerance for traversing, it appears to be silent on the quality of angular radiations. SSIR 2012 clause 25 states that all distances must be checked, however there is not an equivalent statement regarding angles for radiations. It is assumed that while traversing, all angles are read in two faces as this is best practice. However, this may not always be the case, as there is a belief that electronic instruments are adjusted to compensate for the face left/face right error, although some would also argue this compensation includes pointing errors. It is much better to have a well adjusted instrument and take multiple readings. With Automatic Target Recognition (ATR) and motorised instruments it is just as quick to read three arcs, which introduces redundant observations to allow checking.

Is it reasonable to apply the same angular tolerance to all radiations from a station as is applied to the station? If this is the case and there are a lot of stations, the angular tolerance would be very small. However, if there are few stations, the tolerance is rather large by comparison (see Table 3). Should there be a set tolerance for all radiations? Is there an expected tolerance for any survey measurement already present in the profession but not documented yet? Some would argue if it falls in the material of a standard fence then it is okay. There is also a belief if the value of the land is high then tolerance is tighter than lower valued land.

Historically, surveyors used the parallel and square offset method until it was possible to easily measure longer distances, which allowed the transition to radiations. The old method kept radiations short to less than 30 m as a norm. While it is possible to measure longer radiations with a chain, it was not normally done. SSIR 2012 clause 63 states that no RM will reference any point more than 30 metres from the mark. This also adds weight to the 30-metre radiation theory. Table 5 equates angular variation to error ellipse over 30 metres (this is twice as large as an angular error because there is no backsight considered; all of the variation is applied to the foresight). Angular variation is not related to pointing error. However, this is an interesting table to consider when determining the size of allowable limits for radiations.

Table 5: Angular variation at 30 m (angle variation = 30 tan(Delta Angle)).

Delta Angle	**Angle Spread**	**Obs Dist**	**Angle Variation**
Min Sec	**Min Sec**	**m**	**m**
00’ 05”	00’ 10”	30	0.001
00’ 15”	00’ 30”	30	0.002
00’ 30”	01’ 00”	30	0.004
00’ 45”	01’ 30”	30	0.007
01’ 00”	02’ 00”	30	0.009
01’ 25”	02’ 50”	30	0.012
01’ 30”	03’ 00”	30	0.013

4.4 Traverse Misclose Requirements

SSIR 2012 clause 26 deals with survey misclose and is the third component to a cadastral survey traverse. This is a check on the survey as a whole as opposed to the previous two accuracy statements, which are for individual components of measurements. How this is applied to a GNSS survey is also yet to be determined unless it is a GNSS survey that is undertaken in a traverse methodology with each line measured independently of the previous line.

Can this be used to help define how accurate a radiation should be? Consider a 30 m radiation and suppose the check distance method from SSIR 2012 clause 25 is a small traverse of two other lines of 30 m. There is now a total traverse length of 90 m and an allowable misclose of 0.025 m under the SSIR 2012. Table 6 shows the relationship between traverse length and allowable error.

Table 6: Allowable misclose from survey regulations (all values in metres).

	1:8,000 Level	**1:6,000 Undulating**	**1:4,000 Steep**	**1:3,000 Mountainous**	**15mm+100ppm**
Dist	**1933**	**1933**	**1933**	**1933**	**1990 / 2012**
100	0.013	0.017	0.025	0.033	0.025
200	0.025	0.033	0.050	0.067	0.035
250	0.031	0.042	0.063	0.083	0.040
500	0.063	0.083	0.125	0.167	0.065
1,000	0.125	0.167	0.250	0.333	0.115
2,500	0.313	0.417	0.625	0.833	0.265
5,000	0.625	0.833	1.250	1.667	0.515
10,000	1.250	1.667	2.500	3.333	1.015

Again it is interesting to look at the comparison between old and new. The data in Table 6 seems to indicate that new technology is less capable to measure short lines yet better at measuring longer lines as there is a greater acceptable error for short traverses, but a smaller acceptable error in long traverses. That is if the 1933 values are a true representation of ability or whether they are the expectation of measurement quality.

4.5 Error Ellipses

By comparing the errors allowed in the SSIR 2012 for distance and angle, the angular error is much less. This results in a long skinny ellipse. This is very different from the GNSS error ellipse, which is round. Assuming a 9-second angular error, Table 7 shows the resulting error ellipse for various distances based on the discussion so far.

Table 7: Comparison of angle and distance errors according to SSIR 2012 (all values in metres).

9 Sec Angle Error vs. Dist		
	Calc	**Reg's**
Dist	**Ang**	**Dist Tol**
10	0.000	0.011
30	0.000	0.012
50	0.001	0.013
100	0.001	0.015
250	0.003	0.023
500	0.005	0.035
750	0.008	0.048
1,000	0.011	0.060
2,000	0.022	0.110

4.6 Error Ellipse Direction

Now that there is an understanding of the size of the error ellipses and the reasons why these are the shape that they are, consider the result of observing the same point from two stations so that the two radiations are perpendicular to each other. It can be argued that this is the best geometry to have a check radiation as it has the least error due to lines not intersecting at acute angles. By the current theory, the regulations for radiations of 30 m allow an error of 0.012 m in distance, however there is no tolerance in angle. An intersecting radiation of 30 m perpendicular to the first radiation is allowed the same tolerance but in the opposite axis. The resulting error ellipse is a circle with a radius of 0.012 m, yet this does not comply with the regulations as it fails the angular requirement. On the other hand, taking the angular argument it passes both tests, however it is unrealistic to say it is possible to measure without error. Similarly, with regard to survey misclose, while it is possible to measure three lines 30 m long, it is hardly professional to say it is only accurate to ±0.024 m.

There would appear to be a need for the regulations to define the acceptable tolerance for a radiation, in terms of its proximity to any other radiation. Currently the regulations define radiations with regard to how well they are measured from the traverse and the size of the traverse. The tolerance must be considered in two stages. Firstly with a complete disregard of any equipment used and with sole concern of the integrity of the cadastre. Secondly, with consideration of the available equipment to ensure achievable limits are set. This would be a benefit for both traditional survey methods and allow the link to GNSS.

5 REDUCING ERROR SIZE AND IMPROVING ACCURACY

Every measurement has errors. Checking measurements has a dual benefit: it finds gross errors and also improves the accuracy of the initial measurement, provided there was no gross error and the two measurements are of equal accuracy. For every additional measurement the accuracy is increased. However, this is not a linear process. Is there an optimum? The expected error from multiple observations can be expressed as (x = error of a single observation):

$$\text{expected error} = 1/\sqrt{((1/x)^2 + (1/x)^2 + (1/x)^2)} \quad (1)$$

From Table 8, it can be shown that the starting error of one observation is 20 mm. However, by taking a second observation the error is not halved but it is reduced. To halve the error four observations are necessary. To halve that again requires a total of 16 observations. Therefore it would appear that the ideal number of observations is four to get the most benefit with least effort. As an example, a radiation distance read twice in face left and twice in face right achieves a better accuracy or smaller error than a single reading with a higher accuracy instrument. With modern instruments this is very easy to automate.

Table 8: Example of point errors for multi-observations.

No Obs	Error (mm)	
1	7	20
2	4.95	14.14
3	4.04	11.54
4	3.50	10
16	1.75	5

6 POINT ERROR VS RELATIVE ERROR

Every point measured has its own error. However, the error of a line as relative error is not as simple as adding the two point errors together. The relative error is calculated by the following formulae. This could also be reversed to find the allowable point error from a line tolerance. The relative error can be calculated from point errors as (see Table 9 for examples):

$$\text{relative error} = \sqrt{(x^2 + x^2)} \quad (2)$$

$$\text{point error} = \sqrt{(z^2/2)} \quad (3)$$

where x = error of a single observation and z = error of a line.

Table 9: Example of line error from point errors (all values in millimetres).

Line Error	Point Error
4.24	3
5.66	4
7.07	5
8.49	6
9.90	7
11.31	8
12.73	9
14.14	10

7 DETERMINING POINT SEPERATION FOR GNSS POINTS

Consider Figure 1 again, but this time from a GNSS perspective. The points ABC are now (or about to be) measured with GNSS with an estimated point error. This point error can be converted to a relative error and used to calculate the missing variables to be tested against the SSIR 2012. This can be achieved a few ways, e.g. calculate the angle *E/4* from Figure 1 and compare this result to the SSIR 2012 value or use the *E/4* value and the estimated relative error to calculate the minimum point separation *X* from Figure 1.

8 EXPECTED ERRORS FOR CURRENT TECHNOLOGY

Current technology is manufactured to meet the standards set in ISO 17123. Parts 3 and 4 refer to theodolites. For the test undertaken by this standard a confidence level of $1-\alpha = 0.95$ is assumed (Zeiske, 2004). Table 10 shows point error ellipses for points measured relative to GNSS Continuously Operating Reference Stations (CORS), using single-base Real Time Kinematic (RTK) from the closest CORS as well as using Network RTK (NRTK). The error ellipses are not dependant on the distance between the points being measured in the local vicinity of the survey, but are generally dependent on the distance to the surrounding CORS. For example, two points 100 m apart will have an error dependent on the distance to the nearest CORS. It is important to note that the values stated in Table 10 refer to NRTK cells of different sizes (Janssen and Haasdyk, 2011).

Table 10: RTK and NRTK 95% confidence interval deviation from mean (in metres) – interpolated from graphs shown in Janssen and Haasdyk (2011).

Dist to CORS	**0.01 km**	**6 km**	**12 km**	**15 km**	**22 km**	**41 km**	**50 km**
RTK	0.008	0.015	0.022	0.029	0.024	0.027	0.050
NRTK	0.007	0.013	0.013	0.025	0.013	0.025	0.035

Table 11 has been constructed by calculating the line error budgets from manufacture specifications and adding centring tolerances. Then the values were converted to a point tolerance from the line tolerance calculated. This table assumes the instrument is on a tripod and the reflector is on a bipod. The purpose is to allow some comparison to the error ellipses in Table 10, remembering the distances between points should be read from Table 11. The author acknowledges this is not a true comparison, as it is a comparison between field data and manufacturer's specifications, however it does show the generic expected accuracies of each instrument.

The expected error ellipse for static GNSS is one of the key drivers behind this paper. The author has limited experience with static GNSS reductions. From reading various sources, possible errors in the region of ± (10 mm + 2 ppm) at 95% are expected, yet other sources suggest errors of 18 mm at 95% for lines up to 1 km. It will be interesting to investigate the ability of static GNSS for lines below 500 m in length.

Table 11: Theoretical point error budgets for total stations (all values in metres).

Spec	2” 2mm / 2ppm		3” 3mm / 3ppm		5” 5mm / 5ppm	
Dist	**Angle**	**Dist**	**Angle**	**Dist**	**Angle**	**Dist**
10	0.004	0.004	0.004	0.004	0.004	0.005
30	0.004	0.004	0.004	0.004	0.004	0.005
50	0.004	0.004	0.004	0.004	0.004	0.005
100	0.004	0.004	0.004	0.004	0.004	0.005
250	0.004	0.004	0.004	0.005	0.006	0.006
500	0.005	0.004	0.006	0.005	0.009	0.006
750	0.006	0.004	0.009	0.005	0.013	0.007
1,000	0.008	0.005	0.011	0.006	0.018	0.008
2,000	0.014	0.006	0.021	0.007	0.034	0.011

9 LOOKING AHEAD: PROVING THE THEORY

This is all well and good in theory but how does it work in real life out in the field? To test the ability of GNSS to measure or derive angles, a test area has been selected to allow the points to be measured by both methods and the difference in angles compared. The test site is a large triangle with sides approximately 400 m long with two triangles inside it, having sides of 150 m and 250 m. Each angle will be measured by both methods on the same day. The method for measuring the angle will be the same as a standard survey, i.e. total station measuring three rounds. GNSS static observations will be collected for 10 minutes observed twice at least 30 minutes apart. The three sides will be measured with GNSS, processed and adjusted using least squares. This will estimate an error ellipse for each point. RTK measurements will also be made for comparison. Each triangle will be read as a separate observation. Therefore three independent angles will be measured each time. The test will be repeated many times to get an average expected result.

The second test will be a traverse test where GNSS will be used to measure each line independently. Both angular misclose and closure misclose will be calculated. This test will use both static GNSS and RTK/NRTK as independent traverses.

10 CONCLUDING REMARKS

Firstly it must be emphasised that the purpose of this paper is not to discredit GNSS, which is recognised as being a very useful tool used in the appropriate circumstances. What those circumstances are is what is being considered. From the above discussion, it would appear that under the current regulations GNSS is not capable of measuring angles where the vertices are closer than approximately 1 km. This requires three observations being less than 6 km to the closest base station or the use of a quality static survey with small error ellipses. These long baselines are not practical or useful from a field perspective in cadastral surveying. The long baselines are a result of the combination of the uncertainty of the point measured and the angular tolerance in the regulation. From examination of the SSIR 2012, it would appear that there needs to be more discussion regarding all of the tolerances in regard to the cadastre, not the ability of the current technology. However, some regard must be taken to consider the technology to ensure achievable limits are set, even though this may require multiple observations. There is also a need to devise a point tolerance (like the SP1 class system) to allow radiations to be included in the regulation rather than an assumption that they are covered by virtue of the traversing standards. It will be interesting to process the results of the field tests and determine the likely and expected angular results when using GNSS to measure or derive angles, particularly in the range below 500 m.

ACKNOWLEDGEMENTS

Greg Dickson and Les Gardner, both of Land and Property Information, and Kevin Thompson of Trade & Investment, Crown Lands are gratefully acknowledged for their assistance in the preparation of this paper.

REFERENCES

Dickson G. (2012) Control surveys: Why things are the way they are and not the way you think they should be!, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Wollongong, Australia, 19-21 March, 12-28.

Janssen V. and Haasdyk J. (2011) Assessment of Network RTK performance using CORSnet-NSW, *Proceedings of International Global Navigation Satellite Systems Society Symposium (IGNSS2011)*, Sydney, Australia, 15-17 November, 18pp.

LPI (2013) Surveyor General's Direction No. 9: GNSS for Cadastral Surveys, http://www.lpi.nsw.gov.au/surveying/publications/surveyor_generals_directions (accessed Jan 2014).

NSW Legislation (2014a) Surveying and Spatial Information Regulation 2012, http://www.legislation.nsw.gov.au/viewtop/inforce/subordleg+436+2012+cd+0+N (accessed Jan 2014).

NSW Legislation (2014b) Surveying and Spatial Information Regulation 2006 (repealed), http://www.legislation.nsw.gov.au/maintop/view/inforce/subordleg+530+2006+cd+0+N (accessed Jan 2014).

NSW Legislation (2014c) Surveying Regulation 2001 (repealed), http://www.austlii.edu.au/au/legis/nsw/repealed_reg/sr2001243/ (accessed Jan 2014).

NSW Legislation (2014d) Surveyors (Practice) Regulation 1996 (repealed), http://www.austlii.edu.au/au/legis/nsw/num_reg/sr19961996429332.pdf (accessed Jan 2014).

Zeiske K. (2001) Current status of the ISO standardization of accuracy determination procedures for surveying instruments, *Proceedings of FIG Working Week 2001*, Seoul, Republic of Korea, 8-10 May, 9pp.