Current Status of EDM Calibration Procedures in NSW

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ABSTRACT

In Australia, the legal basis for a national system of units and standards of measurement of physical quantities is provided by the National Measurement Act 1960. Under this Act, the Surveyor General of New South Wales is a verifying authority for reference standards of length measurements and responsible for ensuring that surveyors use verified measuring equipment. To this end, the Surveying and Spatial Information Regulation 2012 requires surveyors to verify their Electronic Distance Measurement (EDM) equipment in relation to an Australian standard of measurement of length at least once a year. In order to assist the profession in meeting this requirement, Land and Property Information (LPI) provides and maintains several EDM baselines across the state. LPI is currently in the process of improving this infrastructure by upgrading existing baselines and building new baselines for the calibration of EDM instruments. This paper presents the current status of EDM baseline infrastructure in NSW and outlines the data processing performed by LPI in regards to EDM calibrations. The EDMCAL program currently employed by LPI is described and compared to a popular spreadsheet calculation generated by the University of New South Wales. It is shown that both of these software tools generate comparable results. Finally, LPI's new online EDM baseline booking system is introduced. This online system should now be used by surveyors to book access to all EDM baselines in NSW in order to allow efficient and effective use of existing and future baseline infrastructure.

KEYWORDS: *EDM calibration, EDMCAL, baseline infrastructure, online booking system, legal metrology*.

1 INTRODUCTION

Metrology is the science of measurement and its application. It includes all theoretical and practical aspects of measurement, independent of the measurement uncertainty and field of application (JCGM, 2012). Legal metrology covers activities resulting from statutory requirements and concerning measurement, units of measurement, measuring instruments and methods of measurement that are performed by competent bodies (OIML, 2000). This incorporates all measurements carried out for any legal purpose, including measurements that are subject to regulation by law or government decree.

In Australia, the legal basis for a national system of units and standards of measurement of physical quantities is provided by the National Measurement Act 1960 (Australian

Government, 2013a). This Act is administered by the National Measurement Institute (NMI), which may in turn appoint organisations as verifying authorities under the provisions of Regulation 73 of the National Measurement Regulations 1999 (Australian Government, 2013b). The office of the Surveyor General of New South Wales (NSW) has been so appointed as a verifying authority for length measurement standards.

In NSW, practising surveyors are subject to the Surveying and Spatial Information Act 2002 (NSW Legislation, 2014a) and the Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2014b). The latter states, for instance, that a surveyor must not use any Electronic Distance Measurement (EDM) equipment unless it is verified against the state primary standard of measurement of length by using pillared baselines, at least once every year and immediately after any service or repair. This instrument verification establishes traceability of its measurements to the national standard.

In this context it is important to explain the difference between the terms verification and calibration. The International Vocabulary of Metrology defines these two terms as follows (JCGM, 2012):

- *Verification* is the provision of objective evidence that a given item fulfils specified requirements. When applicable, measurement uncertainty should be taken into consideration. Verification in legal metrology pertains to the examination and marking and/or issuing of a verification certificate for a measuring system.
- *Calibration* is an operation that, under specified conditions, in a first step, establishes a relation between the quantity values (with measurement uncertainties provided by measurement standards) and corresponding indications (with associated measurement uncertainties) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. This may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

In other words, verification allows surveyors to know the acceptability of their measurement results against expectations (e.g. the manufacturer's stated performance criteria) and whether further actions need to be taken in regards to their processes. Calibration is the process of comparing a measured value to a known value, e.g. by comparison to a standard of the physical quantity length.

The verification of an EDM baseline is carried out periodically with precise EDM instrumentation carrying a current Regulation 13 certificate issued by NMI (the associated meteorological equipment is also calibrated against industry standards). This process determines the 'true' inter-pillar distances and establishes traceability because the EDM baseline becomes a subsidiary standard of the International Metre. The calibration of a surveyor's EDM instrument on a verified baseline determines the corrections that need to be applied to the instrument in order to obtain the 'true' inter-pillar distances, thereby establishing traceability of its measurements to the national standard.

In order to assist the surveying profession in meeting their legal requirements, the Surveyor General has established several EDM baselines throughout New South Wales. On behalf of the Surveyor General, Land and Property Information (LPI) is currently in the process of improving this infrastructure by upgrading existing baselines and/or building new baselines for the calibration of EDM instruments.

This paper presents the current status of EDM baseline infrastructure in NSW and outlines the data processing performed by LPI in regards to baseline verifications and EDM calibrations. The EDMCAL software currently employed by LPI is described and compared to a spreadsheet calculation generated by the University of New South Wales. Finally, a new online EDM baseline booking system is introduced to allow efficient and effective use of the baseline infrastructure in NSW.

2 CURRENT EDM BASELINE INFRASTRUCTURE IN NSW

The Surveyor General has established several EDM baselines consisting of between four and seven concrete pillars throughout NSW. Current best practice has established that EDM baselines should consist of at least five (and preferably six or seven) pillars to increase the number of distances observed (i.e. higher redundancy), thereby allowing a more reliable determination of the instrument correction. As a result, LPI is in the process of rationalising and improving its EDM baseline infrastructure by upgrading existing baselines to include more pillars and/or building new 7-pillar baselines.

Figure 1 illustrates the location of the 16 EDM baselines presently maintained in NSW. The new 7-pillar Seaham baseline (constructed in December 2013) replaces the 4-pillar baseline at Newcastle, which will cease to be maintained by LPI in August 2014 (but will continue to be used for teaching purposes by the University of Newcastle). It is planned to upgrade the 4-pillar Armidale baseline to include seven pillars, and contracts have been signed to establish a new 7-pillar baseline at Coffs Harbour (replacing the 4-pillar baseline at Grafton). In addition, efforts are underway to establish new 7-pillar baselines at Wollongong (replacing the existing 4-pillar baseline) and the South Coast (replacing the 4-pillar baselines at Nowra and Bega).

Figure 1: Location of current EDM baselines in New South Wales.

All EDM baselines in NSW (current and those under construction) follow the Heerbrugg design, which features an almost equal distribution of the distances measured in all combinations over the baseline length as well as over the unit length of the EDM and permits the detection of all distance-dependent errors, including cyclic errors (e.g. Schwendener, 1972; Rüeger, 1996). For a detailed description of the substantial issues that need to be considered in the design and construction of a state-of-the-art EDM baseline, the reader is referred to Ellis et al. (2013). Depending on the location of the baseline, additional environmental aspects may have to be considered in some cases (Janssen, 2012).

LPI verifies these baselines on a 2-yearly basis and makes the current measurement reports available on the LPI website (LPI, 2014a). In accordance with the appointment as a verifying authority for length measurement standards, the least uncertainty quoted for the verified inter-pillar distances is currently 0.5 mm + 1.3 ppm at the 95% confidence interval. The field procedures prescribed for EDM calibrations in NSW are documented in Surveyor General's Direction No. 5: Verification of Distance Measuring Equipment (LPI, 2009). It should be noted that the accurate observation of meteorological data is essential for a reliable EDM calibration. An error in the measurement of 1ºC in temperature or 3 millibars in atmospheric pressure will cause a corresponding error in the reduced distance of approximately 1 part per million (ppm).

3 EDMCAL

Naturally, the processing of EDM calibrations can be performed in different ways and with different tools. The standard mathematical methods involved have been described in various textbooks (e.g. Rüeger, 1996; Harvey, 2009). In NSW, a program called EDMCAL has been used for many years by LPI for this purpose. Alternatively, a number of surveyors utilise a spreadsheet calculation developed at the University of New South Wales (UNSW). This section describes the EDMCAL software, while section 4 provides a comparison of EDMCAL and the UNSW spreadsheet in regards to processing outcomes.

3.1 History

The program EDMCAL determines the additive constant (also known as instrument/reflector constant) and scale factor of EDM instruments using the parametric method of a rigorous least squares adjustment. This adjustment includes:

- Data snooping after Baarda (1968) to enable the detection of likely gross errors, i.e. a multidimensional test on the 'a posteriori / a priori' variance factors (test 1) and a one-dimensional test on the ratios of 'residual / a priori standard deviation of residual' (test 2).
- A one-dimensional similarity transformation in which the solution of pillar distances from the calibration adjustment is transformed to previously determined pillar distances.

The original program was written in the FORTRAN programming language by J.D. Love as part of an undergraduate student project for the Bachelor of Surveying at UNSW under the supervision of Dr J.M. Rüeger. The project report was submitted in April 1978. Since then, EDMCAL has undergone numerous modifications at LPI. These include:

- Ensuring compatibility with modern operating systems.
- Improving system performance, data structure and output format.
- Providing the possibility to input the EDM's modulation frequency, carrier wavelength and unit length as an alternative to the first velocity correction parameters.

- Using the mean of forward and reverse distance observations as the distance measurement between pillars, if applicable.
- Output of individual corrections applied to the slope distances, i.e. approximate instrument/reflector constant, atmospheric correction, slope correction, height (or datum) correction and chord-to-arc correction.
- Generation of a baseline database containing verification data on all baselines in NSW.
- Additional optional output to confirm the results, i.e. scale factor computation by linear regression and output of a HAVOC (Horizontal Adjustment by Variation Of Coordinates – see LPI, 2011) input file that can be used to compute the scale factor.

The current version 5.1 of EDMCAL was created in December 2013. The mathematical and statistical procedures have been thoroughly tested over many years. During the most recent update, the mathematical algorithms used to determine the atmospheric corrections were improved to make them more readable and provide clear reference to their origin in the source code. The continuing usage and feedback from users may result in additional modifications to the statistical output in order to further improve the interpretation of results.

3.2 Operation

A sample EDMCAL input file is shown in Figure 2. It includes the following information:

- Label for the 'test number' of the program run.
- Baseline number and name.
- Observation date.
- Institution/company and operator name.
- Instrument make, model and serial number.
- Reflector make, model and serial number.
- Approximate additive constant.
- Instrument thermometer make, model, serial number and its correction.
- Reflector thermometer make, model, serial number and its correction.
- Instrument barometer and its correction (if barometers are used at the instrument and reflector, this entry should include information on both barometers and the mean barometer correction).
- Instrument standard deviation (generally set to 1 mm + 1 ppm for EDM calibrations) and 'f' factor for variance test (dependent on the number of distance observations and the number of pillars).
- First velocity correction parameters for the EDM (i.e. reference refractive index *VC1* and instrument pressure factor *VC2*) and partial water vapour pressure (default: 15 mb).
- Optional: Modulation frequency (Hz), carrier wave length (nm) and unit length (m) of the EDM.
- Optional: Linear regression option selection.
- Optional: HAVOC input file generation option selection.
- Forward observations including slope distance, height of instrument, height of target, mean atmospheric pressure and mean temperature.
- Reverse observations including slope distance, height of instrument, height of target, mean atmospheric pressure and mean temperature.

```
00 13DS1B13.cal                                   (File Name format: ##=year,AS=your initials,1=edmcal No.1,b##=Baseline code No.)
01 13 NOWRA                                       (Baseline code No. & Name)
02 13/09/13                                       (Date)
03 LPI                                            (Owner)
04 D.Sluys                                        (Operator)
05 TRIMBLE S3 DR                                  (Instrument Make & Model)
50 91210131                                       (Inst. Serial No.)
06 Leica 8812249                                  (Reflector Make, Model & Serial No.)
07 +0.000                                         (Approx. Additive Constant)
71 Thies S/No 17723                               (Thermometer used at instrument)
72 +0.0                                           (correction to thermometer)
73 Thies S/No 17723                               (Thermometer used at reflector)
74 +0.0                                           (correction to thermometer)
75 Negretti & Zambra S/No 932                     (Barometer used at instrument)
76 0.0                                            (correction to Barometer)
08 1.00   1.00                 1  2.200           (Instrument Std Deviation ; 2.200 ="f" factor for variance test)
09 278.3  80.7 15.0                               (Ist Velocity Parameters for inst.; "15" = Partial Water Vapour Press.)
11 1 0.241 2 0.242 150.6548   1 1016.3 13.9       (11=Fwd Obs, Pillar No Inst, HI, Pillar No Ref, HR, Slope Dist, Flag,
12 1 0.240 2 0.240 150.6542   1 1016.5 14.2           Press(mm or mb)(Inst&Ref Mean),Temp (Inst&Ref Mean))
11 1 0.241 3 0.241 317.2696   1 1016.5 13.8       (12=Rev Obs, Pillar No Ref, HI, Pillar No Inst, HR, Slope Dist, Flag,
12 1 0.240 3 0.241 317.2694   1 1016.7 14.6           Press(mm or mb)(Inst&Ref Mean),Temp (Inst&Ref Mean))
11 1 0.241 4 0.240 580.8092   1 1016.9 14.0
12 1 0.240 4 0.240 580.8084   1 1016.4 14.2       *** NOTE:   "HI"   MUST ALWAYS be in columns 6-10
11 2 0.240 3 0.241 166.6788   1 1017.0 13.7                   "HR"   MUST ALWAYS be in columns 14-18
12 2 0.240 3 0.242 166.6786   1 1017.2 14.4
11 2 0.240 4 0.240 430.3018   1 1016.9 14.4
12 2 0.240 4 0.242 430.3012   1 1016.9 14.8
11 3 0.240 4 0.240 263.6996   1 1017.0 14.8
12 3 0.240 4 0.241 263.6992   1 1017.0 15.0
99
```

Figure 2: Sample EDMCAL input file.

The input file is first checked for correctness of the number of pillars and number of observations. The basic principle of EDM instruments is the indirect determination of the travel time of a wave of light from the instrument to the reflector and back. While the speed of light in a vacuum is well known, in practice measurements are (of course) not carried out in a vacuum. The EDM measurements must therefore be corrected for the ambient atmospheric conditions because the velocity of visible and infrared waves changes with temperature, pressure and relative humidity (for light waves, the humidity is usually ignored).

Several corrections are applied to the observed slope distances in order to reduce these to horizontal distances at the height of the lowest pillar: approximate additive constant (if input by the user), atmospheric correction, slope correction, height (or datum) correction, and chord-to-arc correction (generally zero over distances used for EDM calibrations). The standard deviations of the measured distances are then computed. This is followed by the formation and solution of the normal matrix derived from the observations and the output of the results of calibration and data snooping according to Baarda (1968). The 'null' hypothesis is tested for acceptance or rejection.

The reduced distances are used to form observation equations for a least squares adjustment (e.g. Harvey, 2009). The adjustment parameters are the distances from the first pillar to each of the other pillars and the correction to the additive constant, leading to the determination of the additive constant of the instrument/reflector pair used. It is important to note that this additive constant is valid for a particular combination of instrument and reflector only, accounting for the distance-measurement reference points of the EDM instrument and the reflector not being coincident with the vertical axes at either end of the distance.

In order to determine the scale factor (and its ppm equivalent), a one-dimensional similarity transformation is carried out using the calibrated distances as coordinates. The program output is terminated with a brief summary that also provides the differences between the 'known' verified baseline distances and the adjusted distances determined with the EDM instrument under investigation (Figure 3).

```
                                SUMMARY
                                -------

     Test number                    :  13DS1B13.cal
     Baseline used                  :  NOWRA
     Verification date              :  08 AUG 12
     Date of observation            :  13/09/13
     Name of owner                  :  LPI
     Name of operator               :  D.Sluys
     Instrument manufacturer/model:  TRIMBLE S3 DR
     Instrument serial number       :  91210131
     Refl manufacturer,model & S/N:  Leica 8812249
     Approx. inst/refl constant     :   0.0000
     Inst thermometer S/N           :  Thies S/No 17723
     Refl thermometer S/N           :  Thies S/No 17723
     Barometer serial number        :  Negretti & Zambra S/No 932

   No. of pillars on base line:  4  No. of distances observed: 12

       Corrected instrument/reflector constant = -0.0351 metres

              Scale factor = 1.0000014891 (    1.5 ppm )

                   Calibrated Distance   Adjusted Distance  Difference

Pillars 1 to 2           150.4696            150.4695        -0.0001

Pillars 1 to 3           317.0879            317.0862        -0.0017

Pillars 1 to 4           580.7327            580.7321        -0.0006
```

Figure 3: Sample EDMCAL output summary.

4 COMPARISON OF EDMCAL AND UNSW SPREADSHEET

An alternative tool for the calculation of EDM instrument calibrations was developed by Dr B.R. Harvey at the University of New South Wales (UNSW) in form of an Excel spreadsheet (Harvey, 2014). Initially created for teaching purposes in 2006, the spreadsheet is now used by several surveyors for their EDM calibration calculations. The advantage of this spreadsheet is that all equations are visible to the user (rather than hidden in source code) and calculations can be customised for special cases if desired. However, this also means that users are at risk of inadvertently changing calculations. Currently, the spreadsheet allows for the determination of additive constant and scale factor on baselines consisting of between four and eight pillars. A sample calculation of the cyclic error is also included.

It should be noted that the UNSW spreadsheet states the standard deviations and uncertainties (at the 95% confidence level) of the calibration results, while EDMCAL does currently not routinely provide any rigorous uncertainty information. For baseline verifications, LPI determines the measurement uncertainties using an in-house spreadsheet calculation based on the recommendations stated in Bentley (2005) and JCGM (2008).

This section investigates whether the UNSW spreadsheet and EDMCAL provide comparable results in regards to EDM calibrations. Several datasets observed by LPI legal metrology staff during EDM baseline verifications are used for this purpose. The comparison is mainly based on seven verification datasets for each of three EDM baselines: Wollongong (600 m, 4 pillars), Wagga Wagga (535 m, 5 pillars) and Dubbo (765 m, 6 pillars). In the absence of a history of observations on a particular baseline consisting of seven pillars, the comparison also incorporates four datasets recently collected on the 7-pillar baselines at Kingscliff (K, 721 m), Eglinton (E, 849 m) and Lethbridge Park (L, 984 m). The 25 datasets used in this study are summarised in Table 1.

Table 1: EDM baseline verification datasets used in this study.

Dataset	**4 pillars (Wollongong)**	**5 pillars (Wagga Wagga)**	**6 pillars (Dubbo)**	**7 pillars (various)**
1	Jun 2000	Dec 2000	Jun 2000	Mar 2010 (K)
2	Jun 2002	Jun 2002	May 2002	Nov 2012 (E)
3	May 2004	May 2004	Jun 2003	Jul 2013 (K)
4	Nov 2005	May 2006	Oct 2004	Oct 2013 (L)
5	May 2007	Apr 2009	Sep 2006	–
6	May 2011	May 2011	Aug 2008	–
7	Jun 2013	Jun 2013	Aug 2012	–

Generally, for standard EDM calibrations on baselines consisting of seven or more pillars, it is sufficient to observe forward distances only. However, in this case all possible inter-pillar distances were observed in order to provide maximum redundancy for the purpose of baseline verification. Most datasets were collected using a Leica TCA2003 total station, while a Leica TS30 total station was used for all datasets from 2011. Both instruments are similar in regards to the precision stated by the manufacturer (1.0 mm + 1 ppm and 0.6 mm + 1 ppm, respectively) and were set to apply zero instrument corrections. As EDMCAL does not routinely provide rigorous uncertainty information, the comparison is limited to the additive constant and the scale factor (ppm equivalent).

In this context, it should be noted that the UNSW spreadsheet requires the user to input the relative humidity for each measured line in the calculation of the first velocity correction, while this quantity is ignored in EDMCAL. However, LPI staff routinely observe and record these values in the field during baseline verifications, allowing the comparison to be undertaken without the need for estimated or externally sourced values. In this case, the mean humidity value was determined for each dataset and then applied to all measured lines in the UNSW spreadsheet. It is also worth noting that the UNSW spreadsheet requires meteorological data to be corrected before input, while EDMCAL is able to accept the raw observations and apply thermometer and barometer instrument corrections during processing.

The results of the comparison between the additive constants and scale factors calculated using the UNSW spreadsheet (no iteration performed) and EDMCAL are illustrated in Figures 5 and 6, respectively. It should be noted that the first Dubbo dataset (June 2000) was identified as an outlier and removed from the analysis. The results indicate good agreement between the two calculation tools. The additive constants generally agree within 0.3 mm for the 4-pillar (Wollongong) and 5-pillar (Wagga Wagga) baselines, while larger differences of up to 0.8 mm are obtained for the 6-pillar baseline at Dubbo. Much better agreement of 0.1 mm or better is achieved at the 7-pillar baselines, although it should be noted that three of these datasets represent the first verification after construction of the baseline and therefore use their own results as 'known' distances in the processing. The scale factors agree within about 0.5 ppm for the 4-pillar, 5-pillar and 7-pillar baselines and about 1.5 ppm for the 6-pillar baseline.

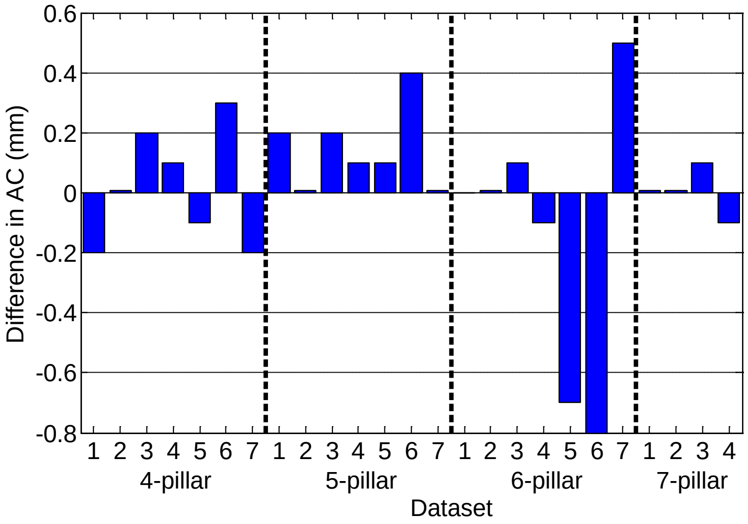

Figure 5: Difference in additive constant (AC) between UNSW spreadsheet and EDMCAL output (mm).

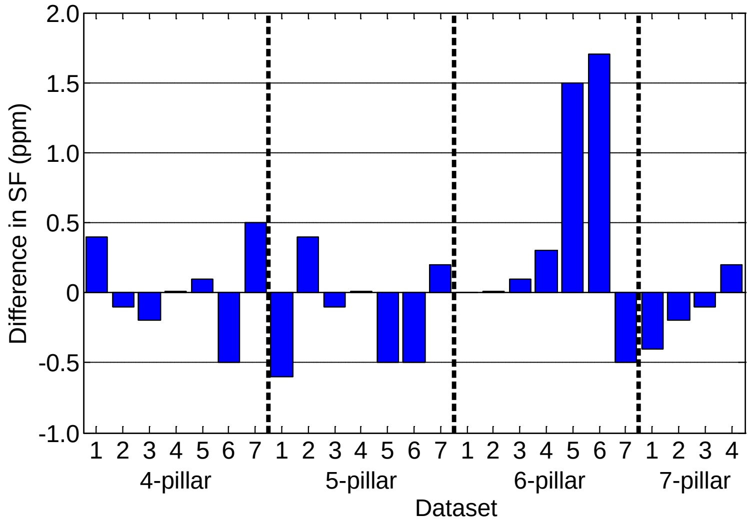

Figure 6: Difference in scale factor (SF) between UNSW spreadsheet and EDMCAL output (ppm).

It is also useful to investigate the differences in the distances relative to the first pillar after the calculated additive constant and scale factor have been applied. As already mentioned, the June 2000 dataset at Dubbo was identified as an outlier and therefore removed from the analysis. Descriptive statistics on the comparison between the output of the UNSW spreadsheet and EDMCAL are summarised in Table 2. A high level of agreement between the two calculation tools is evident, and the stated differences can be assumed negligible for most EDM calibrations in practice.

Table 2: Descriptive statistics of the differences in distances from pillar 1 between UNSW spreadsheet and EDMCAL (all values in mm).

	4 pillars	**5 pillars**	**6 pillars**	**7 pillars**
Min.	-0.2	-0.4	-0.7	-0.6
Max.	0.2	0.7	0.6	0.4
Range	0.4	1.1	1.3	1.0
Mean	0.01	0.03	-0.07	-0.04
RMS	0.08	0.20	0.33	0.19

These results show that the UNSW spreadsheet provides results comparable to EDMCAL processing for general practical purposes. However, it is important to note that recently verified distances must be used as 'known' inter-pillar distances in order to obtain reliable results. Using the latest verification results (i.e. 2012 or 2013) as 'known' distances for the processing of all datasets investigated in this study provided considerable differences not only in the resulting scale factors due to slight pillar movement but also negatively affected the relative comparison between the two calculation tools.

5 ONLINE EDM BASELINE BOOKING SYSTEM

In the past, EDM baselines in NSW were not subject to a booking requirement. Surveyors were generally able to visit a baseline at any time, provided no baseline specific access requirements were in place (e.g. prior approval and/or keys from baseline host required). Particularly at popular baselines, this can result in several surveyors attempting to use the baseline at the same time, thus negatively affecting their productivity and time management (particularly if considerable travel time to the baseline is involved).

In order to avoid these disadvantages, LPI has developed the EDM Baseline Booking System. This free online booking system is now available via the LPI website (LPI, 2014b) and allows registered users to reserve a particular time slot at the desired baseline in advance. The booking process is simple and straightforward, comparable to booking a hotel room online. A help page with instructions on how to use the system and the opportunity to make enquiries or provide feedback are also included.

A screenshot of the booking system's main page is shown in Figure 7. The process consists of the following three simple steps:

1. Select a booking date.
2. Select an EDM baseline.
3. Select an available booking time.

Once the booking is finalised, a confirmation will be sent by email, also outlining the general and baseline specific conditions of use that had to be accepted during the booking process. The user is required to carry a printout of this booking confirmation with them at all times when on the baseline site. This will provide proof of approved access to the baseline for the specified time period.

The EDM Baseline Booking System was launched on 29 October 2013 and should now be used by surveyors to book access to all EDM baselines in NSW in order to allow efficient and effective use of existing and future baseline infrastructure. The booking system will also assist LPI in monitoring the frequency of use of each baseline, thereby allowing more informed decision making in regards to the state's EDM baseline infrastructure in the future.

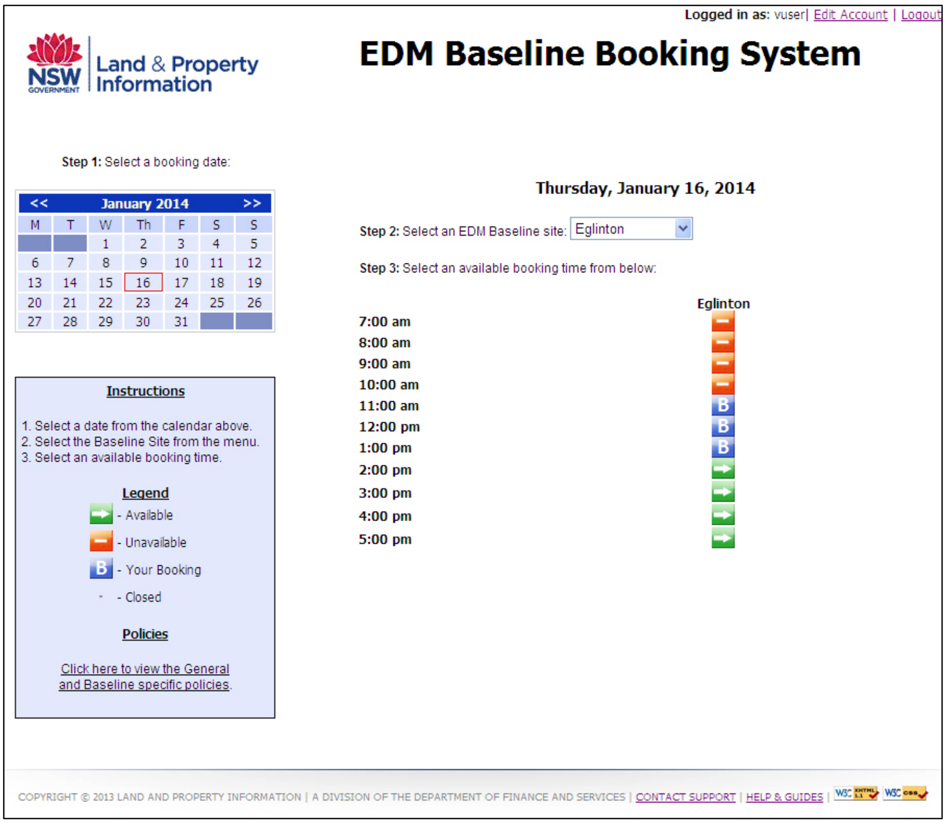

Figure 7: Main page of the online EDM Baseline Booking System (http://lpi.nsw.gov.au/edmbooking).

6 CONCLUDING REMARKS

This paper has briefly described the status of EDM baseline infrastructure in NSW, which is currently being rationalised and improved by upgrading existing baselines to include more pillars and building new 7-pillar baselines. The EDMCAL software used by LPI for the processing of EDM baseline verifications and EDM calibrations was outlined. Based on 25 datasets collected on baselines consisting of between four and seven pillars, it was shown that the EDM calibration spreadsheet developed by the University of New South Wales provides additive constants and scale factors comparable to the EDMCAL output.

Finally, LPI’s new EDM baseline booking system was introduced. This free online system is easy-to-use and should now be utilised by surveyors to book access to all EDM baselines in NSW in order to allow efficient and effective use of existing and future baseline infrastructure. By allowing LPI to monitor the frequency of use of each baseline, the booking system will also assist LPI in making more informed decisions regarding the state’s EDM baseline infrastructure in the future.

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REFERENCES

Australian Government (2013a) National Management Act 1960 (Cth), http://www.comlaw.gov.au/Details/C2013C00612 (accessed Jan 2014).

Australian Government (2013b) National Measurement Regulations 1999 (Cth), http://www.comlaw.gov.au/Details/F2013C00709 (accessed Jan 2014).

Baarda W. (1968) *A testing procedure for use in geodetic networks*, Publications on Geodesy, 2(5), Netherlands Geodetic Commission, Delft, 97pp.

Bentley R.E. (2005) *Uncertainty in measurement: The ISO guide*, Monograph 1: NMI Technology Transfer Series (11th edition), National Measurement Institute, 110pp.

Ellis D., Janssen V. and Lock R. (2013) Improving survey infrastructure in NSW: Construction of the Eglinton EDM baseline, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 187-201.

Harvey B.R. (2009) *Practical least squares and statistics for surveyors*, Monograph 13 (3rd edition), School of Surveying and Spatial Information Systems, University of New South Wales, Sydney, Australia, 332pp.

Harvey B.R. (2014) EDM calibration spreadsheet, available at http://www.surveying.unsw.edu.au/ls/ (accessed Feb 2014).

Janssen V. (2012) Indirect tracking of drop bears using GNSS technology, *Australian Geographer*, 43(4), 445-452.

JCGM (2008) Evaluation of measurement data – Guide to the expression of uncertainty in measurement, Joint Committee on Guides for Metrology, http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf (accessed Jan 2014).

JCGM (2012) International vocabulary of metrology – Basic and general concepts and associated terms (VIM) (3rd edition), Joint Committee on Guides for Metrology, http://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2012.pdf (accessed Jan 2014).

LPI (2009) Surveyor General's Direction No. 5: Verification of Distance Measuring Equipment, http://www.lpi.nsw.gov.au/surveying/publications/surveyor_generals_directions (accessed Jan 2014).

LPI (2011) HAVOC, http://www.lpi.nsw.gov.au/surveying/geodesy/havoc (accessed Jan 2014).

LPI (2014a) EDM baseline certificates, http://www.lpi.nsw.gov.au/surveying/surveying_services/edm_baseline_certificates (accessed Jan 2014).

LPI (2014b) EDM baseline booking system, http://lpi.nsw.gov.au/edmbooking (accessed Jan 2014).

NSW Legislation (2014a) Surveying and Spatial Information Act 2002, http://www.legislation.nsw.gov.au/viewtop/inforce/act+83+2002+cd+0+N (accessed Jan 2014).

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

OIML (2000) International vocabulary of terms in legal metrology, International Organization of Legal Metrology, http://workgroups.oiml.org/tcsc/tc-07/tc-07-sc-04/july-16-18-2013-workshop-and-project-group-meeting/agenda-and-documents-for-discussion-at-the-project-group-meeting/V001-ef00.pdf (accessed Jan 2014).

Rüeger J.M.R. (1996) *Electronic distance measurement: An introduction* (4th edition), Springer, Berlin, 300pp.

Schwendener H.R. (1972) Electronic distancers for short ranges: Accuracy and Checking procedures, *Survey Review*, 21(164), 273-281.