A Proposed Method for Testing Reflectorless EDM

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ABSTRACT

The introduction of Electronic Distance Measurement (EDM) equipment has revolutionised survey practice. The majority of total stations available today are capable of 'reflectorless EDM' measurement, allowing surveyors to measure distances to objects other than traditional reflective targets. This technology increases the versatility of the total station and can improve the safety of field personnel. Surveyors must have a good understanding of the performance limitations of their equipment in order to produce quality work. Over the last decade, a number of studies have investigated the nature of reflectorless distance measurement, including the variable accuracy of measurements to different surfaces. However, there appears to be a lack of guidance to the surveying industry on the use of reflectorless EDM in cadastral surveying within the Australian Capital Territory (ACT). In accordance with Direction 17 of the Surveyors (Surveyor-General) Practice Directions 2013 (No. 1) (ACT), surveyors must ensure that all equipment, including their EDM, is in accurate adjustment, standardised and properly calibrated. Recently, a number of surveyors have enquired if it is possible to test the performance of their reflectorless EDM instrument at the Watson baseline in order to comply with Direction 17. This paper proposes a methodology for testing reflectorless EDM instruments at the Watson baseline. A case study of testing a Sokkia SRX3X total station using a prototype non-cooperative target is presented. Furthermore, the use of reflectorless EDM in cadastral surveys is discussed and recommendations are made.

KEYWORDS: *Reflectorless, target, EDM, cadastral, baseline.*

1 INTRODUCTION

Today's total stations are capable of measuring distances to objects other than traditional reflective prisms. This Electronic Distance Measurement (EDM) functionality is generally referred to as 'reflectorless EDM' measurement and is now another useful piece of equipment in the surveyor's toolbox. Using reflectorless EDM, distances can now be measured to all manner of objects which previously would be difficult to locate with a traditional reflective (cooperative) prism, such as high and inaccessible structures. Sensible application of this technology may lead to productivity gains in field work and the enhancement of the workplace health and safety of survey field parties. Dangerous locations such as working at heights, confined spaces, aggressive dogs, hostile neighbours, vehicular traffic and unstable quarry walls can all now be avoided by the surveyor's assistant. But can these reflectorless distance measurements be relied upon, especially if they are used in a cadastral survey?

Direction 17 of the *Surveyors (Surveyor-General) Practice Directions 2013 (No. 1)* (ACT Government, 2013) requires surveyors who perform cadastral surveys to ensure their equipment is in accurate adjustment, standardised and properly calibrated. To achieve this, a surveyor's EDM must be calibrated at least once every 12 months on a certified baseline established by, or acceptable to, the Surveyor-General. The calibration procedure provides an estimation of the systematic index, scale and cyclic errors that are present in all EDMs (ESDD, 2012).

A review of the available literature indicates that there are many variables associated with the use of reflectorless EDM. Significant measurement inaccuracies may be encountered when observing EDM distances to non-cooperative targets due to the physical characteristics of different materials. These differences may include the colour of the material (Stiros et al., 2007), material reflectance, i.e. whether it is dull or shiny (Rüeger, 2003), the wetness of a target (Höglund and Large, 2003), the angle of incidence of the EDM beam with the target (Rüeger, 2003; Ernst, 2009; Holley et al., 2011), the illumination of the surface (Lambrou and Pantazis, 2010), and the texture of the material (Rüeger, 2003; Ernst, 2009). The measurement characteristics of various materials have been the focus of a number of studies and have not been investigated in this paper. The interested reader should refer to the reference publications for more details.

This paper aims to encourage all surveyors to employ a consistent approach when testing their reflectorless EDM equipment so the results obtained provide a reliable verification. The Watson EDM baseline is used to test three different aspects of the performance of a Sokkia SRX3X total station, i.e. (1) the divergence and alignment of the reflectorless EDM beam, (2) a comparison of a calibration in standard EDM mode and reflectorless mode, both measuring to a standard reflective prism, and (3) testing of the reflectorless EDM measuring to a non-cooperative target.

2 WATSON EDM BASELINE

The EDM baseline maintained by the Office of the Surveyor-General (OSG) is located in the suburb of Watson in the ACT (Figure 1). The baseline is a modification of the original Sprent-Zwart design (Sprent and Zwart, 1978; Sprent, 1980) and consists of 11 forced centring pillars spread over approximately 1,117 m. The baseline is within 0.04 m of being linear over its entire length and all pillars are inter-visible. A certificate under Regulation 13 of the National Measurement Regulations 1999 (Australian Government, 2013) is issued annually by the OSG, whom the National Measurement Institute has appointed as a Verifying Authority for Length (ESDD, 2012). Using a standard reflective prism, surveyors can calibrate their EDMs at the Watson baseline for compliance with Direction 17.

Calibration of measuring equipment should not be confused with the testing of that equipment. Calibration is a more rigorous process where the relationship between an instrument's measurements and a standard of the physical quantity being measured is determined. Calibrating an instrument on a verified EDM baseline allows its distance measurements to be traceable to the international standard of length. On the other hand, equipment testing provides a means of checking that an instrument's measurements are within the manufacturer's stated performance criteria. Due to the almost infinite variability of non-cooperative reflecting surfaces as mentioned above, standard procedures for calibrating reflectorless EDM equipment currently do not exist (Mazalova et al., 2010). Indeed, there is even a lack of standard procedures to test the performance of a reflectorless EDM against the manufacturer's stated accuracy!

Figure 1: Pillars 1, 2 and 3 of the Watson EDM baseline.

Nevertheless, surveyors are still required to know the accuracy obtained by their measuring equipment, and a number of surveyors have made enquiries with the OSG to see if they could test the reflectorless functionality of their EDM at the Watson baseline. The proposed procedure to test the performance of reflectorless EDM equipment, as described below, has been prepared partly in response to these enquiries, and to a certain extent address the lack of guidance to the surveying industry, as perceived by the author, on the use of reflectorless EDM in cadastral surveys. It is emphasised that the methodology presented is not an official calibration and does not provide legal traceability of EDM measurements when taken in reflectorless mode. However, by following the survey procedures described herein, it is believed that surveyors would comply with Direction 17 of the *Surveyors (Surveyor-General) Practice Directions 2013 (No.1)* with regard to their reflectorless EDM equipment.

3 DESIGN OF THE TARGET

Surveying instrument manufacturers use Kodak Grey Card as an unofficial standard when determining the range and accuracy of their reflectorless EDMs (Höglund and Large, 2003; Bayoud, 2006; Stiros et al., 2007). Kodak Grey Card is the recognised standard in professional photography for determining scene reflectance and has two sides, i.e. grey and white. The correct names for the two sides of the card are “Kodak Grey Card 18% Reflective” and “Kodak White Card 90% Reflective”, with 18% and 90% reflectance across the visible spectrum respectively. The 18% reflectance of the grey side was chosen for photography because everyday scenes and objects average approximately 18% reflectivity of light (Höglund and Large, 2003). Additionally, Kodak Grey Card is an approximate realisation of a Lambertian scattering surface, where the radiant light leaving the surface is constant for any angle of reflectance (Jensen, 2005), and in the field of remote sensing Kodak Grey Cards have been shown to be a good reflectance reference standard (Milton, 1989; Peddle et al., 2001).

The design of a non-cooperative target was an important consideration for this study, as it is envisaged that a robust target could be used as a future 'standard' target for the purpose of testing reflectorless EDMs at the Watson baseline. Kodak Grey Card was chosen as the non-cooperative surface. A prototype target was designed and specially constructed, based on a standard Sokkia APS34 triple prism with the reflective prisms removed. A 6 mm thick sheet of medium-density fibreboard (MDF) was mounted to the frame of the triple prism, then the 204 mm x 254 mm Kodak Grey Card affixed to the MDF, with the grey side exposed. The face of the Kodak Grey Card was marked to allow for repeatable face-left/face-right pointing. Markings were also added to each side of the MDF target for consistent height measurements. The prototype non-reflective target used in the case study is shown in Figure 2.

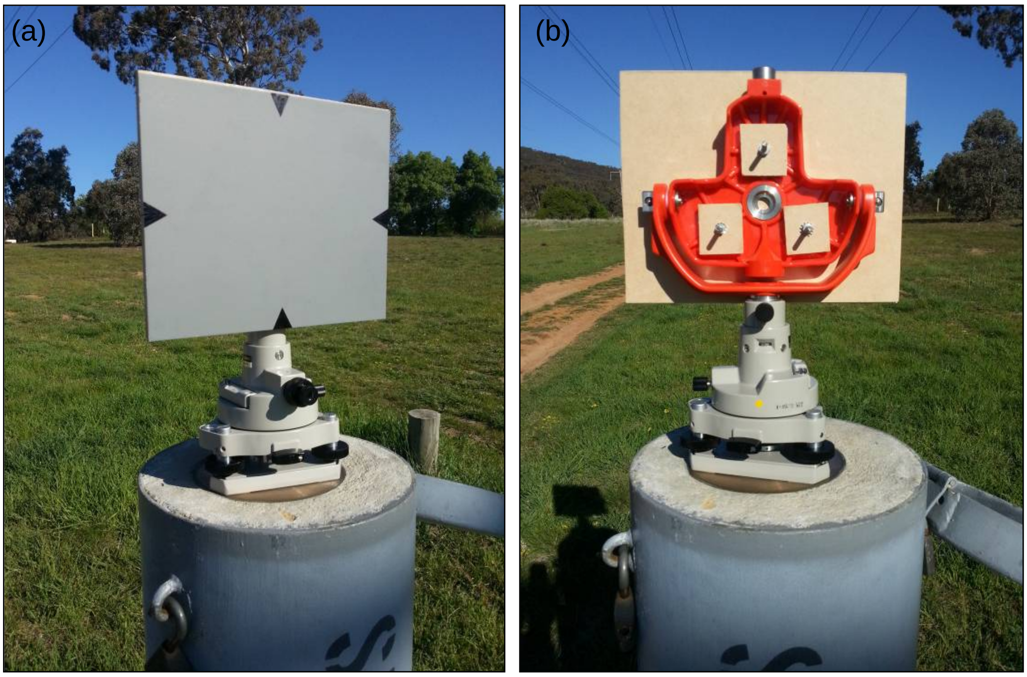

Figure 2: (a) Front face and (b) rear of the non-cooperative target used in this study.

4 CASE STUDY: TESTING OF SOKKIA SRX3X AT WATSON BASELINE

For this case study, measurements were made at the Watson EDM baseline using a Sokkia SRX3X total station (Figure 3) during October 2013, with favourable environmental conditions encountered throughout the testing. The Regulation 13 certificate on the Watson baseline was current to 15 August 2014. The surveyor must have confidence in the reliability of their reflectorless EDM measurements (Holley et al., 2011), hence this case study comprises three parts, i.e. (1) determining the size, shape and alignment of the reflectorless EDM beam, (2) comparing the calibrations of standard and reflectorless EDM measurements observed to a standard reflective prism, and (3) testing the reflectorless EDM measurements to the prototype non-cooperative target.

The manufacturer's specified standard deviation (1σ) of the SRX3X for standard EDM observations to a reflective prism is ± (1.5 mm + 2 ppm), while in reflectorless mode it is ± (2 mm + 2 ppm) for distances less than 200 m and ± (5 mm + 10 ppm) for distances between 200-350 m. For distances between 350-1,000 m, the standard deviation in reflectorless mode is stated as ± (10 mm + 10 ppm). It should be noted that these reflectorless distance standard deviations are to Kodak Grey Card 90% Reflective (Sokkia Topcon Co. Ltd, 2006), while other instrument manufacturers sometimes use the 18% Reflective side, as was used in this case study.

Figure 3: Sokkia SRX3X total station used in the case study.

4.1 Determining EDM Beam Dimensions

Due to non-selective scattering of electromagnetic waves in the atmosphere (Jensen, 2005), the reflectorless beam diverges as its distance from the EDM increases (Höglund and Large, 2003), resulting in reflectorless EDMs measuring an average distance to the 'footprint' on the target that is illuminated by the EDM beam (Rüeger, 2003). Therefore it is important for the surveyor to know the size and shape of the reflectorless beam at various distances.

Rüeger (2003) describes a simple procedure for determining the effective beam size, shape and its alignment with the optical cross hairs of the total station's telescope. Since this information is essential for reliable reflectorless measurements, tests should be carried out at a number of distances for both horizontal and vertical alignment. The stepped timber block used in this study was constructed to Rüeger's specifications and is shown in Figure 4. Additionally, the edge of the front of the block was marked with black texta to aid in sighting of the step. By following Rüeger's test procedure, it was determined that at 337 m (pillar 1 – 6) the reflectorless beam of the Sokkia SRX3X was approximately 35" of arc, both horizontally and vertically. Therefore, the size of the 'footprint' of the reflectorless beam approximates a circle with a diameter of 0.057 m at 337 m, and would comfortably fit on the 204 mm x 254 mm Kodak Grey Card. Furthermore, at the time of testing the reflectorless EDM beam was found to be closely aligned with the telescope's cross hairs.

Figure 4: Timber block used to determine the beam dimensions and alignment.

4.2 Calibration to a Cooperative Target

The following two calibrations were observed at the same time to a Sokkia APS12 single prism using the Sprent-Zwart observation technique described in the OSG's EDM Calibration Handbook (ESDD, 2012). Distances were first observed in the standard mode, and then the instrument was switched to reflectorless mode before the prism moved to the next pillar. By observing the standard EDM and reflectorless EDM measurements back-to-back, the influence of any differences in atmospheric conditions between the calibrations was virtually eliminated. Rüeger (2003) states that observing in reflectorless mode to a reflective prism allows distances of a few kilometres to be measured. In this test, the Sokkia SRX3X easily measured the full length of the Watson baseline (1,117 m) in reflectorless mode.

The two sets of observations were processed using the Baseline v5.6.0.6 software to estimate the systematic index and scale errors of the EDM/prism pair using least squares analysis. The mathematical model for the EDM distance correction contains a cyclic component, however modern EDMs rarely contain any significant cyclic error (Klinge, 2007). A comparison of the systematic errors estimated for the two measurement modes is given in Table 1.

Table 1: Comparison of standard against reflectorless EDM modes to an APS12 reflective prism.

	Standard EDM		**Reflectorless EDM**	
	Value	**Uncertainty** (95% confidence interval)	**Value**	**Uncertainty** (95% confidence interval)
Index Error	-2.1 mm	0.7 mm	-5.8 mm	0.7 mm
Scale Error	1.2 ppm	2.0 ppm	0.5 ppm	2.0 ppm
Cyclic Error	Insignificant		Insignificant	
A posteriori variance factor	0.767		0.679	

In reflectorless mode, the individual distance observations within each set had a larger range when compared to the standard mode. However, the reflectorless least squares adjustment gave an overall better fit to the known (Regulation 13) inter-pillar distances, as indicated by the lower a posteriori variance factor. Note that OSG's least uncertainty of measurement, as specified by the National Measurement Institute (NMI) is 0.6 mm + 2 ppm. Uncertainties of calibrations performed on the Watson baseline cannot be reported below this limit, hence the scale error uncertainties for both calibrations are reported as 2 ppm.

4.3 Reflectorless Testing to Non-Cooperative Target

The observation routine chosen for the reflectorless EDM testing is a modification of the routine used on Heerbrugg designed baselines, as described by Schwendener (1972) and LPI (2009). Generally, the observation routine followed the procedures described in the EDM Calibration Handbook (ESDD, 2012), with the following exceptions:

- Distance measurements were made in both face-left (FL) and face-right (FR) to eliminate any error associated with the non-alignment of the reflectorless EDM beam with the optical cross-hairs, in conjunction with the target not being absolutely perpendicular with the line-of-sight. Although the testing performed in section 4.1 showed these to be in good alignment, five slope distances were measured in FL and five measured in FR for each inter-pillar distance.
- Ambient temperature and atmospheric pressure were entered into the SRX3X prior to observing each inter-pillar distance, thereby allowing the on-board software to apply the first velocity correction to the raw distances.
- Although the Watson baseline has 11 pillars, only pillars 1 to 6 were occupied for the reflectorless EDM testing to the non-cooperative target. The measuring sequence involved setting the SRX3X on pillars 1 to 6 in turn, resulting in 24 observed inter-pillar distances. As is the case for a standard EDM calibration at the Watson baseline, the distances between pillars 1, 2 and 3 (with chainages of 0, 5 and 7.5 m) were not observed as these short distances may exhibit non-linear behaviour, as found in the testing performed by Lichti and Lampard (2008).

The observations were again processed using the Baseline v5.6.0.6 software. The least squares adjustment of the SRX3X distance measurements observed in reflectorless mode to the non-cooperative target achieved a reasonable-to-good level of redundancy. The adjustment returned an a posteriori variance factor of 0.242. The chi-squared test on the variance factor can be used as a reliable statistical test for determining if the observations have been correctly weighted, provided that there are no gross errors in the observations (Klinge, 2007). In this adjustment, the chi-squared test on the variance factor returned a fail result, which suggests that the weighting of the observations may be tightened.

A review of the residuals and standardised residuals shows there are no gross or systematic errors present within the observations. All residuals are small and range from -1.5 mm to +1.3 mm. There are no flagged standardised residuals, therefore all values are within the 3σ rejection criterion. If the observations contain only random errors and correct assumptions for the input weights have been made, then the standardised residuals will follow the shape of a normal distribution curve (Klinge, 2007). The histogram of the standardised residuals (Figure 5) is only slightly skewed and is close to a normal distribution, further suggesting that the data are free of observational errors. However, the histogram does show some degree of kurtosis suggesting that the weighting of the observations may be tightened, as also indicated by the failure in the chi-squared test. In this instance, the a priori standard deviations assigned to the observations, i.e. ± (2 mm + 2 ppm), were considered appropriate and were not amended. The statistical analysis and the review of the residuals and standardised residuals as discussed above were deemed acceptable. The systematic errors of the reflectorless EDM, as estimated by the least squares adjustment, are shown in Table 2.

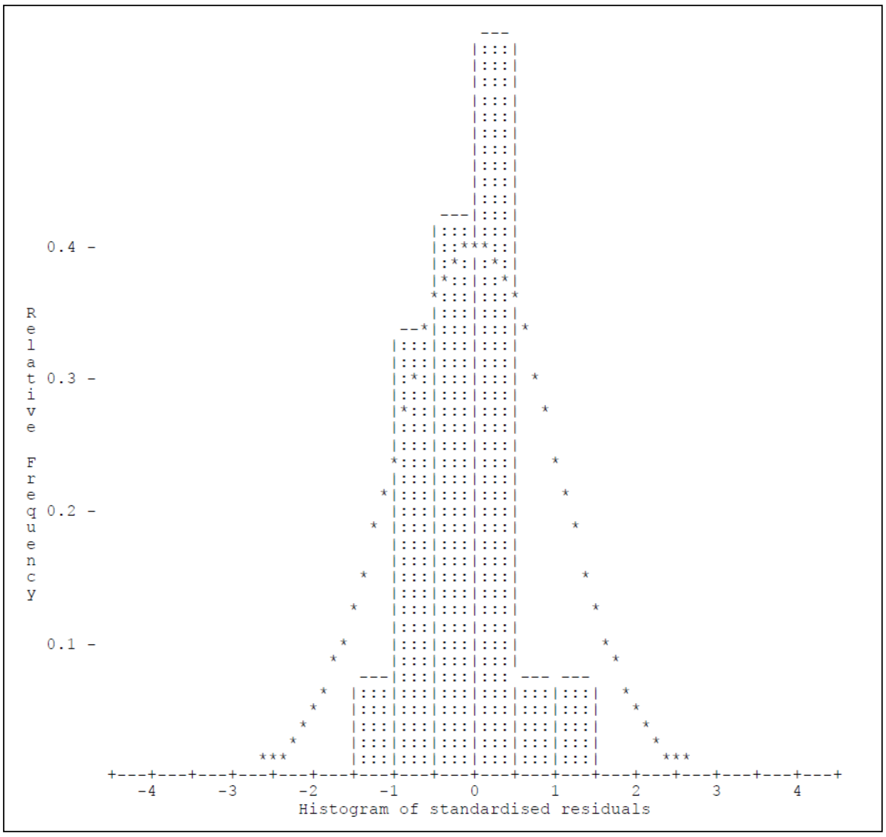

Figure 5: Histogram of standardised residuals.

Table 2: Estimated systematic errors of the reflectorless EDM.

	Value	**Uncertainty** (95% confidence interval)
Index Error	+32.0 mm	0.6 mm
Scale Error	-1.9 ppm	3.5 ppm
Cyclic Error	Insignificant	
A posteriori variance factor	0.242	

The design of the non-cooperative target introduces an unavoidable additive constant, as the face of the Kodak Grey Card is not aligned with the vertical axis of the Sokkia APS34 triple prism mount. Measurements taken with a calliper show this physical offset to be +31 mm ± 1 mm. Consequently, all reflectorless EDM distances measured to this non-cooperative target must be increased by 31 mm. Applying this additive constant gives an index error of the reflectorless EDM as +1.0 mm ± 1.6 mm (at 95% CI). The full reflectorless EDM instrument correction (IC) in millimetres (to be added to the instrument reading) is:

$$IC = 1.0 - (1.9 \times 10^{-6})\, D \qquad (1)$$

where D = distance (m)

Therefore, this test confirms that the index and scale errors of this Sokkia SRX3X total station are within the manufacturer's stated performance for reflectorless measurements observed to the Kodak Grey Card.

5 DISCUSSION AND RECOMMENDATIONS

5.1 Review of the Case Study

Any misalignment of the reflectorless EDM beam with the optical cross hairs, in conjunction with a non-cooperative target not being absolutely perpendicular with the line-of-sight, will introduce a systematic error in all reflectorless distance observations. It is strongly recommended that surveyors, as an absolute minimum, perform the testing described by Rüeger (2003) to check the alignment of the reflectorless EDM beam, along with the size and shape of the beam's 'footprint' at various distances. These checks should be performed as part of the instruments initial acceptance testing, and during its annual calibration. While this part of the case study was performed at the Watson baseline, in practice, it can be carried out at any convenient location.

The second part of the case study shows that it is possible to calibrate the reflectorless EDM component of the Sokkia SRX3X with a standard reflective prism, while using the traditional observation routine employed at the Watson baseline. At the time of testing, its performance was commensurate with the performance of the standard EDM beam, however the test clearly demonstrated that extreme care must be taken when mixing observations between non-cooperative targets and standard survey prisms, as the index errors are not the same. For the SRX3X used in this study, the reflectorless EDM mode measures 3.7 mm longer than standard mode. Forgetting to swap the measurement mode in the total station will introduce a constant error in distances observed to standard prisms. Note that the method of observing reflectorless EDM measurements to a standard reflective prism has not been formally investigated by NMI or the National Association of Testing Authorities (NATA), therefore it cannot yet be considered an official 'calibration' of the reflectorless EDM.

The result of the third part of this study shows that it is possible to test reflectorless EDMs on the Watson baseline using a non-cooperative target, and for the SRX3X investigated, the reflectorless EDM performed within the manufacturer's specifications. The proposed testing methodology was restricted to pillars 1 to 6 on the baseline. Including additional pillars would increase the number of inter-pillar distances required to be measured, thus increasing the time required to perform the observations and may dissuade some surveyors from carrying out the test. It is recognised that limiting the range of the test to 337 m reduces the effectiveness of determining an EDM instrument's ppm error component. However, experience suggests that reflectorless EDM is most commonly used in short range applications, and distances observed by this SRX3X would not be significantly affected by the ppm error. It is recommended that the OSG prepare a Surveyor-General's guideline to assist surveyors who wish to check the performance of their reflectorless EDM against the manufacturer's specifications.

It is recognised that the case study only tested reflectorless EDM measurements to a reflective prism and to Kodak Grey Card. Surveyors should also test their reflectorless EDM against the different materials they are likely to encounter (e.g. concrete, timber, steel and tile) as each material has an individual reflectance characteristic and will therefore have its own specific additive constant (Widjajanti et al., 2008). Stiros et al. (2007), Ernst (2009) and Holley et al. (2011) present practical methods to perform these comparisons.

5.2 Use of Reflectorless EDM in Cadastral Surveys

It has been shown that reflectorless EDM instruments can be tested against a primary standard of length in order to determine their accuracy. The uncertainties of the SRX3X measurements determined in this case study are 0.7 mm + 2 ppm to a standard reflective prism and 1.6 mm + 3.5 ppm to the non-cooperative target (both at the 95% confidence interval), and are well within ACT cadastral distance accuracy requirements, being 6 mm + 30 ppm for urban surveys and 10 mm + 50 ppm for rural surveys (ACT Government, 2013). However, given the variable reflective nature of different materials, should reflectorless EDM measurements be used in cadastral surveys?

With the widespread availability of reflectorless EDM instrumentation and with the current lack of guidance for its proper use, it is recommended that the *Surveyors (Surveyor-General) Practice Directions 2013 (No. 1)* be amended to restrict the use of reflectorless EDM measurements in cadastral surveys to instances where reduced measurement accuracies may be tolerated. Such features that could be permitted to be located by reflectorless EDM include some occupations (e.g. walls with rough faces), inaccessible structures and natural features. Objects located using reflectorless EDM measurements should require additional field checks, over and above the traditional check measurements required under Direction 31(1), in order to confirm their positional accuracy. However, in order to preserve the integrity of the cadastre, monuments and well-defined structures on or near the boundary, as well as cadastral reference marks and survey control marks, must not be located using reflectorless EDM measurements. In all cases, the surveyor must understand the capabilities and limitations of their EDM equipment and use their professional judgement to determine when reflectorless EDM measurements are appropriate.

Furthermore, under Direction 64, surveyors are required to indicate on their Plan of Survey all lines measured or derived by Global Navigation Satellite System (GNSS) observations. Given the numerous variables associated with non-cooperative targets that may be encountered in the field, perhaps surveyors should also be required to indicate the objects that were measured with reflectorless EDM on their Plan of Survey. At the very least, this information should be included in an accompanying report.

6 CONCLUDING REMARKS

Testing of reflectorless EDM equipment should be performed prior to its initial use by the surveyor, in order to determine the size, shape and alignment of the reflectorless EDM beam. Failure to do so may lead to erroneous reflectorless EDM distance observations. The results of the study indicate that it is possible to calibrate an instrument in reflectorless mode while observing to a reflective prism, and also to test the performance of reflectorless EDM to a non-cooperative target by taking a series of measurements at the Watson baseline.

Reflectorless EDM is acceptable for some survey applications where lower measurement accuracies may be considered fit-for-purpose. However, given the number of variables of reflecting surfaces encountered during survey field work, consideration should be given to amending the *Surveyors (Surveyor-General) Practice Directions* to include a new clause that limits the scope of reflectorless EDM measurements in cadastral surveys.

For those surveys where reflectorless distances are incorporated, surveyors are strongly encouraged to adopt best practice and include independent redundant observations in order to confirm their reflectorless distance observations and to comply with Direction 31(1). Furthermore, it is recommended that surveyors who use reflectorless EDM measurements test their EDM equipment annually in accordance with the procedures described herein, in order to provide confidence in the results of their surveys and to comply with Direction 17.

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