Evaluation of Manual Log Measurement Errors and Its Implications on Harvester Log Measurement Accuracy

Martin Strandgard

ABSTRACT

Previous studies of harvester measurement accuracy assumed traditional manual log measurements were accurate and represented true log dimensions, which relies heavily on the assumption that logs are regular in shape. The objective of this study was to quantify the level of variability in manual log measurements and consider its impact on harvester calibration and accuracy assessments. Log length was measured along the top and each side and small-end diameter with callipers, a diameter tape, and a steel ruler in two radiata pine stands near Mt. Gambier in Southern Australia. Observed variability in manual log measurements was sufficient to affect harvester accuracy studies and calibration. Length variability on different sides of a log occurs mainly from non-square log ends. Differences due to observer were minor. Diameter measurement variability occurs mainly from the effect of stem eccentricity on each instrument, which is dependent on its number of stem contact points. Callipers have fewer contact points than a diameter tape and hence more variability. This variability was evident in comparisons between observers and instruments.

Harvester accuracy studies need to minimize manual measurement variability to identify harvester measurement errors. Length should be measured on the same side measured by the harvester. Diameter should be measured with a diameter tape in preference to callipers as they have greater stem contact and less variability.

Harvester calibration needs to minimize manual and harvester measurement variability to identify harvester measurement bias with the least number of logs to minimize the time required for these activities. In addition to the above suggestions relating to harvester accuracy study measurements, logs selected for calibration must be the most uniform in shape available to highlight harvester measurement biases.

Keywords: *measurement accuracy, forest harvesting, calibration, Pinus radiata, Australia*

Introduction

Forest harvesting worldwide has moved from manual log bucking to mechanical harvesting to improve worker safety and productivity (Murphy et al. 2004). The shift to mechanical harvesting has seen efforts to optimize the log mix cut from each tree by estimating its characteristics from initial length and diameter measurements and predicting the log combination that maximizes value while fulfilling market requirements.

Optimization requires accurate harvester log measurements. Harvester measurement errors can significantly impact value recovery through downgrading of undersized logs to lower value products and poor selection of log combinations from each stem (Marshall 2005, Murphy et al. 2005). Murphy (2003), in a study of 39 mechanical log-making systems, found on average 20 percent of potential value was lost through measurement inaccuracy and poor log selection. Although there are no comparable published Australian studies, observations and the use of similar equipment suggest similar levels of loss are likely to occur.

Harvester measurement accuracy is assessed through comparison with manual log measurements. Previous harvester accuracy studies have assumed traditional manual log measurements are accurate and represent true log dimensions (Andersson and Dyson 2002, Sondell et al. 2002, Nieuwenhuis and Dooley 2006,). But, until details of manual measurement errors are known, manual and harvester measurement differences cannot be solely ascribed to harvester errors.

Manual log measurement errors result from instrument errors, poor measurement technique, and flawed assumptions. Manual measurement errors can also arise from errors such as misreading an instrument or recording a wrong value. These types of error were not investigated. Instrument errors are mainly caused by wear and tear such as stretching of tape measures and loose calliper arms. Temperature induced changes in steel tape measure length can also occur. Poor measurement techniques include instrument misalignment (i.e., not measuring perpendicular or parallel to the log), measuring over bumps or branch stubs, and applying incorrect tension to tapes and callipers. While these are important potential error sources, their effect can be minimized by regular equipment maintenance and training of personnel.

The key flawed assumption in harvester accuracy studies and calibration procedures is that logs are regular in shape. This assumption is implicit in the traditional approach of taking single log length measurements. In reality, bumps, branch stubs, sweep, and non-square log ends can affect log length measurements. Stems are also rarely circular in cross section (Biging

The author is Research Fellow (mnstra@unimelb.edu.au), School of Forest and Ecosystem Science, University of Melbourne, Burnley Campus, Richmond, Victoria, Australia. This paper was received for publication in August 2008.

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and Wensel 1988) due to eccentricity, or fluting and buttressing, particularly near the stem base (Singleton et al. 2004), which can affect diameter measurements. Stem eccentricity is believed to be the major factor affecting diameter measurement precision near Mt. Gambier in southeastern Australia where the study took place. Radiata pine trees in this area commonly lean to the southeast and are eccentric in cross section with the longer axis in the direction of lean (Fielding 1940).

Differences in log length and diameter measurements related to log shape irregularity are not measurement errors in the traditional sense as there is no single value of length and diameter of an irregular log. Given this, the term variability is used in this paper to describe measurement differences.

The objective of this study was to quantify the level of variability in manual log measurements and consider its impact on harvester calibration and accuracy assessments.

Material and Methods

Study Sites

Log measurements were made in two mature radiata pine (*Pinus radiata* D. Don) clearfell stands managed by ForestrySA (the South Australian Forestry Corporation) and located north-west of Mt. Gambier in southeastern Australia. Details of study sites, harvesters, and sample tree and log numbers are given in **Table 1**. Trees were selected by the operator, processed into logs according to ForestrySA sawlog standards (length within ± 5 cm and minimum small-end diameter [SED] of 150 mm) and positioned for easy measurement. Four nominal log lengths were cut at Brennans (375 cm, 495 cm, 520 cm, and 615 cm) and three at Capfirco (375 cm, 555 cm, and 615 cm).

The harvesters were near new and had been operating for a short period of time before the trial; both had recently been calibrated.

Measurements

Harvester calibration attempts to correct measurement bias whereas harvester accuracy studies assess measurement variability. Log length and SED measurements were checked for bias with t-tests (or nonparametric tests where data were not normally distributed); absolute measurement differences and standard deviations (SD) were analyzed to quantify variability. Stem eccentricity and taper were estimated from manual measurements as they were believed to be important factors in log diameter and length variability, respectively.

Standard practice in harvester accuracy studies and calibration procedures has been to take single log length measurements without regard to the side measured by the harvester (Makkonen 2001, Andersson and Dyson 2002). The unstated assumption is that log length is the same irrespective of the side measured. To test this assumption, the length of each log was measured to the nearest millimeter using a steel tape measure along the top and then as close to 90° to either side around the log from the top as could be achieved. Sides were denoted 'right' and 'left' from the operator's perspective facing the log's small end. Ideally the length of the side measured by the harvester would have been measured but it could not be identified or accessed on many logs. Top and side length measurements were compared using Wilcoxon Matched Pairs Signed-Ranks test ($\alpha = 0.05$). SDs of length differences between all of the sides at each site were compared using Levene's test ($\alpha = 0.05$).

SED was measured overbark to the nearest millimeter on each log with three instruments:

- callipers held horizontally[1],
- a diameter tape marked in π cm was used to estimate diameter from girth measurements, and
- a steel ruler to measure minimum and maximum diameters across the log face to calculate stem eccentricity.

SED measurements were made as close to the log end as practical. In some cases, knots or bumps required calliper and diameter tape measurements to be made further along the log. Diameter measurement instruments were compared using paired t-tests ($\alpha = 0.05$).

Stem eccentricity was calculated by dividing the minimum SED by the maximum SED (Karkkainen 1975, Kellogg and Barber 1981). Eccentricity was averaged by log position in the stem and 50 mm diameter classes to check for patterns. Eccentricity at each site was compared using a t-test on the ranked data ($\alpha = 0.05$).

[1] Although the mean of two measurements at right-angles is preferred, single measurements are not precluded by most harvester operator manuals.

Table 1. ~ *Harvester types and sample sizes for Capfirco and Brennans study sites.*

Site	Harvester	Planting year	SQ[a]	SPH[b]	BA[c] (m^2/ha)	DBHOB[d] (mm)	Sample trees	Sample logs
Capfirco Mt Gambier forest. 15 km NW of Mt Gambier	Timberjack 1470. H290 harvesting head	1975	3	200	33	460	36	119
Brennans Mt Burr Forest. 44 km NW of Mt Gambier	Valmet 475EX on a Caterpillar base. Rosin RD977 harvesting head	1954	6	104	29	600	20	97

[a] SQ = site quality of the area of the stand where the measured logs were located. SQ was assessed at age 9.5 by ForestrySA staff using the procedure described in Lewis et al. (1976).
[b] SPH = stems per hectare.
[c] BA = basal area.
[d] DBHOB = estimated mean diameter at breast height over bark. Derived from SPH and BA estimates.

Taper (mm/m) was calculated for each log, except butt logs, by dividing the difference in each log's end diameters by the mean of the manual log lengths for the top and each side. The previous log's SED (diameter tape measurements) was assumed to equal the large end diameter of the next log. Median taper at each study site was compared using a Mann-Whitney test ($\alpha = 0.05$).

At Capfirco, all length and diameter measurements were repeated by two observers. Observer results were compared using paired t-tests ($\alpha = 0.05$). Site and instrument comparisons were made using results averaged between observers. Data were tested for normality and equality of variance to determine the appropriate statistical tests to be applied. Measurements were analyzed with Minitab v. 15.1.1.0 and MS Excel 2002.

Results

Diameter

Observer comparison

The comparison of observer diameter measurements at Capfirco is summarized in **Table 2**. Diameter tape measurements were significantly different between observers ($p = 1.5 \times 10^{-10}$). The bias is clearly visible in **Figure 1(a)**. The three largest differences (17, 14, and 13 mm) were excluded to test their influence and the difference remained significant. These values were retained for further analysis and discussion. Calliper measurements were noticeably more variable than diameter tape measurements (**Fig. 1 and Table 2**).

Instrument comparison

Diameter tape and calliper measurements were significantly different ($p = 1.7 \times 10^{-6}$) at Capfirco (averaged across both observers) and not at Brennans (**Table 2 and Fig. 2**).

Eccentricity and log SED

Eccentricity (minimum/maximum SED) across all of the logs at each site was significantly different between sites ($p = 0.045$). Eccentricity values averaged by log number within stem or 50 mm diameter classes were relatively consistent and did not produce an observable pattern at either site. This consistency implies that the difference between minimum and maximum diameters increases with increasing diameter.

Length

Observer comparison

At Capfirco, inter-observer log length differences were small (**Table 3**). The only significant difference was on the left side of the logs ($p = 0.01$).

Top and side length comparison

At both sites, top length measurements were significantly different from measurements to either side (Capfirco: top vs. left $p = 0.0001$; top vs. right $p = 0.03$. Brennans: top vs. left $p = 0.02$; top vs. right $p = 0.03$); left and right side length measure-

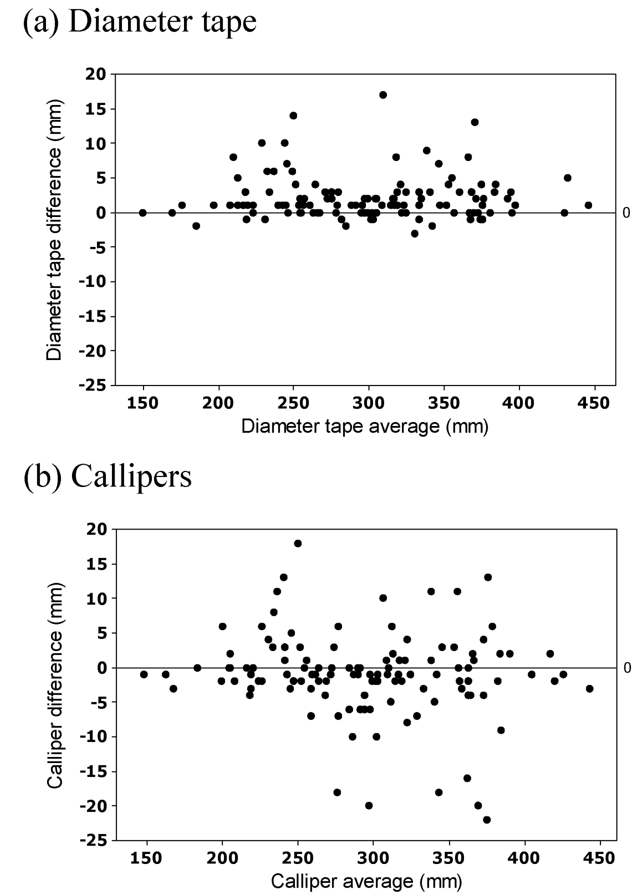

Figure 1. ~ *Difference between each observer's small-end diameter (SED) measurements against the mean of the observers' SED measurements at Capfirco. Measurements are overbark in mm.*

Table 2. ~ *Means and SDs of inter-observer and inter-instrument diameter measurement differences at Capfirco and Brennans.*

	Capfirco		Brennans	
	Mean	SD	Mean	SD
	- - - - - - - - -	(mm)	- - - - - - - - -	
Inter-observer calliper differences	1	6	--	--
Inter-observer diameter tape differences	2[a]	3	--	--
Diameter tape and Calliper differences	3[a]	7	1	9

[a] Significantly different ($p \leq 0.05$).

Table 3. ~ *Means and SDs of inter-observer length measurement differences at Capfirco and Brennans.*

	Mean	SD
	- - - - - - - - (mm) - - - - - - - -	
Top side	0	3
Left side	1[a]	3
Right side	0	3
Differences between all sides	0	3

[a] Significantly different ($p \leq 0.05$).

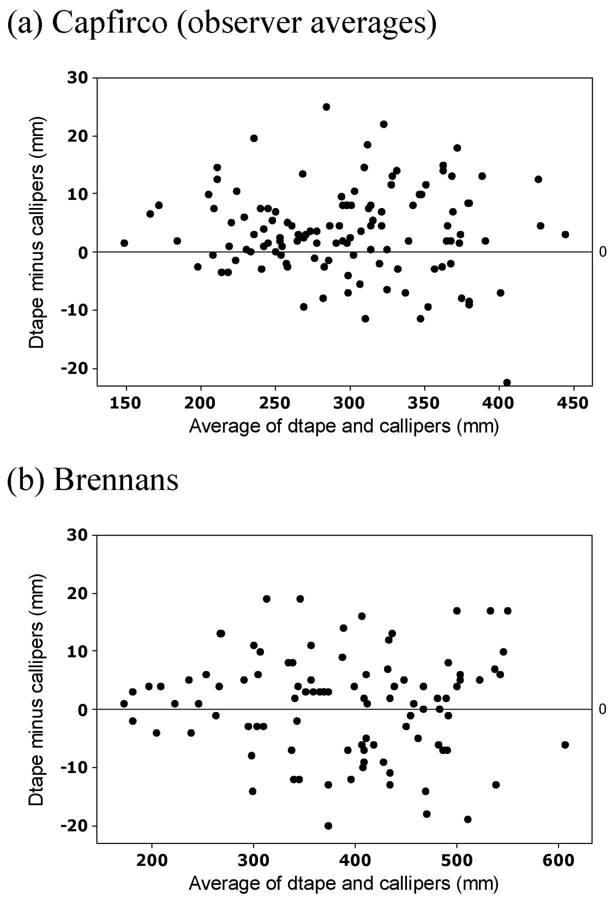

Figure 2. ~ *Diameter tape minus calliper measurements against the mean of diameter tape and calliper measurements at (a) Capfirco and (b) Brennans. Measurements are overbark in mm.*

ments were not significantly different. Mean length differences at both sites were small (**Table 4**).

Absolute length differences and SDs at both sites were analyzed to examine variability (**Table 5**). At both sites absolute length differences were predominantly ≤ 10 mm although a proportion was ≥ 20 mm. Butt logs had a disproportionate number of larger (≥ 20 mm) length differences, particularly at Capfirco. Removing butt log data at both sites significantly reduced the SD (Capfirco $p = 9 \times 10^{-10}$; Brennans $p = 0.0002$).

Median taper

Median taper calculated for all of the logs (except butt logs) was significantly greater at Brennans (11 mm/m) than at Capfirco (10 mm/m) ($p = 0.0001$).

Discussion

Variability in manual length and diameter measurements is believed to be strongly related to log diameter and taper, which are in turn related to tree size, age, and stand density. Improvements in genetics and silviculture have seen radiata pine rotation lengths in Australia decline from 40 to 45 years to 27 to 30 years (Powell et al. 2005) which has probably also reduced variability in manual log measurements through reductions in mean diameter and taper. Lower variability at the younger Capfirco site compared with the older Brennans site supports this view. Although variability was reduced at Capfirco, it was not eliminated and still had a potential impact on manual measurements.

Table 4. ~ *Means and SDs of top and side manual length measurement differences at Capfirco and Brennans.*

	Capfirco[a]		Brennans	
	Mean	SD	Mean	SD
	- - - - - - - - - (mm) - - - - - - - - -			
Top versus left side	–3[b]	8	–4[b]	16
Top versus right side	–2[b]	8	–3[b]	15
Left versus right side	2	13	1	18
Differences between all sides	–2	10	–3	16

[a] Observer averages.
[b] Significantly different ($p \leq 0.05$) within a site.

Table 5. ~ *Absolute length differences and SDs of signed length differences between all log sides at Capfirco and Brennans.*[a]

	Capfirco	Brennans
Length difference range (mm)	0 to 65	0 to 89
Length differences ≤ 10 mm	77%	61%
Length differences ≥ 20 mm	6%	15%
Proportion of butt logs	30%	21%
Length differences ≥ 20 mm on butt logs	86%	36%
SD (mm)	10a	16b
SD excluding butt logs (mm)	7c	13d

[a] Values not marked with the same letter are significantly different ($p \leq 0.05$).

Diameter

Potential factors affecting manual diameter measurement variability were observer differences, measurement assumptions, and measurement technique errors.

Observer comparison

Mean differences between observer diameter measurements were small (**Table 2**). Differences between observer diameter tape measurements were probably in part due to differences in tension applied by each observer. Subsequent tests found tension differences can account for 1 mm diameter difference between observers. Inter-observer differences could be reduced by standardizing measurement techniques.

Observer calliper measurement differences were more variable than diameter tape differences (**Table 2**) which concurs with the findings of McArdle (1928) in an inter-observer comparison measuring diameters of standing trees. Measurement inconsistency between field workers using callipers is one reason diameter tapes are often preferred in forest inventory (Schreuder et al. 1993). Potential causes of calliper measurement variability include:

- Non-perpendicular measurement. Callipers held at an angle across a log measure the widest point of an ellipse whereas a diameter tape used at an angle measures the (smaller) mean diameter of the ellipse (Schreuder et al. 1993).
- Surface irregularities at contact points. Surface irregularities directly increase calliper diameter measurements whereas they increase the circumference of a diameter tape measurement which is divided by π to estimate diameter, reducing the effect.
- Two measurements at right angles may not be in the same plane (i.e., offset along the log).

Instrument comparison

Diameter measurement instruments are based on the principle that logs are circular in cross section, which is rarely the case. Harvester accuracy studies and calibrations assume differences between manual and harvester diameter measurements are caused by harvester errors whereas in most cases a proportion of the difference will result from stem eccentricity. Eccentricity's effect on an instrument is related to the instrument's number of log contact points. The more contact points the more consistent (precise) are diameter measurements on eccentric stems, as log orientation has less effect. Callipers have the least contact points (two), followed by harvester heads (three), and diameter tapes (entire stem). Single calliper measurements of eccentric stems can measure at any point between the minimum and maximum diameters. Averaging two calliper measurements at right-angles (not tested in this study) doubles the contact points to four and has been found to markedly reduce variability of calliper measurements on eccentric stems (Chacko 1961, Gregoire et al. 1990), at the cost of increases in both measurement time (Binot et al. 1995), and potential for measurement error. Eccentricity at both sites was in the range found in other studies (Karkkainen 1975, Kellogg and Barber 1981). In contrast with previous studies, eccentricity along the trunk was relatively consistent with no pattern observed in changes in eccentricity with diameter or log position. Consistency in eccentricity means the difference between the minimum and maximum diameters increases with increasing diameter. This is likely to mean that calliper measurement variability will increase with increasing diameter.

Length

Potential factors affecting manual length measurement variability were observer differences, measurement assumptions, and measurement technique errors.

Observer comparison

There was little variability between observer length measurements (**Table 3**) suggesting this is a negligible source of variability in manual length measurements.

Top and side length comparison

Although the majority of length differences between different log sides were ≤ 10 mm, 15 percent of the length differences at Brennans and 6 percent at Capfirco were ≥ 20 mm. Many of the large length differences were on butt logs, particularly at Capfirco. Removing butt logs markedly reduced SD at both sites (**Table 5**).

The main cause of log length differences is believed to be non-square log ends which are probably the result of stem taper and sweep causing the harvester head to tilt as it is pressed against the tree, which causes the sawblade to cut at an angle (**Fig. 3**). Changes in the degree of tilt at either end of a log result in length differences. Consistent tilt at both ends of a log results in non-square log ends but no length differences. The effect is greatest in butt logs probably due to their greater rate of taper change (particularly if buttresses are present), greater sweep, and larger diameter (which produces greater length differences for a given angle of harvester head deflection). Although sweep was not measured, a t-test on data from a recent study of 400 logs from 10 stands aged 23 to 44 in the same area (McKinley et al. 2004) showed sweep was significantly greater in butt logs (p = 0.0009) which concurs with the literature (Lavery 1986, Ivkovic et al. 2006).

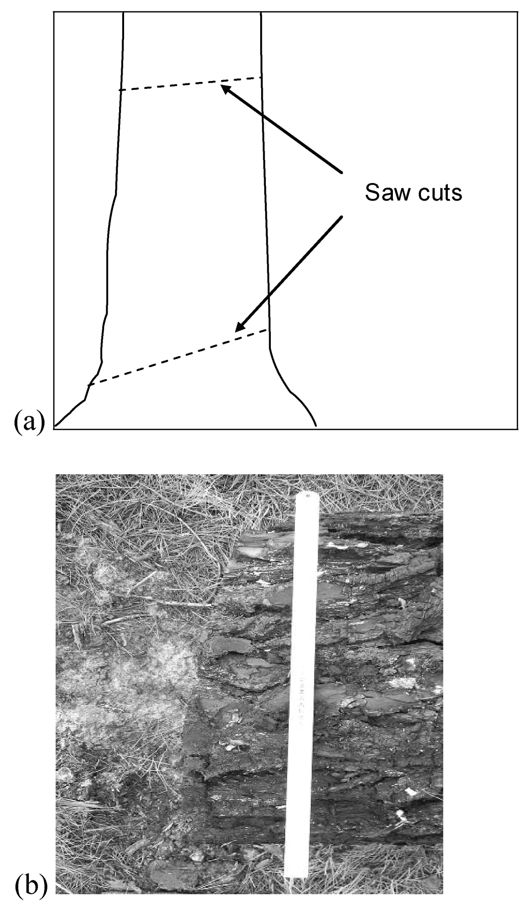

Figure 3. ~ *(a) Greater taper, sweep, and diameter at the tree base is believed to tilt the harvester head more than higher up the tree. (b) Off-square log end at Brennans.*

Mean length measurements for the top of the logs at each site were significantly shorter than those on either side whereas the mean side log lengths were not significantly different (**Table 4**). This is consistent with the logs being cut off-square and mainly orientated with the shortest side uppermost. As the shortest side is believed to be that closest to the harvester during cross-cutting, this in turn implies the logs' orientation changed little after cross-cutting.

Significantly larger length differences at Brennans compared with Capfirco probably resulted from the larger mean diameter at breast height over bark (DBHOB) and taper (hence greater harvester head tilt) at Brennans where trees were older and stand density was less (**Table 1**). Although not measured, buttressing was probably also greater at Brennans as it increases with age and tree size.

Measurement technique

Calculations of the effect of poor manual length measurement technique related to sweep, taper, branch stubs/bumps, and holding the tape non-parallel to the log show it to have only a slight impact on length measurements. Logs with sweep should be measured along the trunk to emulate the harvester but are usually measured between the log ends with the tape not contacting the log in between. The potential effect of this error can be calculated assuming the log forms an arc and the tape a chord across the arc. Using published information on ForestrySA's maximum allowable sweep (approximately 20 mm/m for SED > 400 mm), the maximum length difference from measuring the chord rather than the arc would be 6 mm for a 6.1-m log. Measuring along the log rather than parallel to the log's central axis produces only a slight length error even on a highly tapered log. There is no impact in practice as both harvester and manual techniques measure along the log. Significant deflection of the tape by bumps and branch stubs and holding the tape measure non-parallel to the log should not occur if good measurement techniques are applied. Minor deflections and skewing of the tape will result in errors of several millimeters at most.

Implications to Harvester Accuracy Studies and Harvester Calibration

Harvester accuracy studies and harvester calibration assume no variability in manual log measurements. Any variability that occurs is ascribed to harvester measurement errors.

Harvester accuracy studies assess harvester log measurement performance by comparing measurement variability between harvesters relative to manual measurements. Studies that ignore manual measurement variability may give poorer ratings of harvester measurement performance as the rating will combine actual harvester performance and manual measurement variability. Manual measurement variability must be minimized to obtain a reasonable performance estimate.

Harvester calibration attempts to reduce bias in harvester log measurements relative to manual measurements. Harvester and manual log measurement variability may obscure bias. The greater the variability, the larger the log sample size required to detect bias and the greater the loss of productive time spent in harvester calibration. Hence manual and harvester log measurement variability must be minimized to minimize calibration time.

The results suggest that the variability in measurements between observers and between diameter measurement instruments and on different log sides is random and will average out close to zero given a sufficient sample size. Sample size is dependent on variability.

Length measurement variability is less critical than diameter measurement variability as length is measured to the nearest centimeter and Australian log length specifications generally have a tolerance of ± 5 cm (James 2001) whereas diameter is measured to the nearest millimeter and has no tolerance.

Variability between observer length measurements was negligible (SD = 3 mm) compared with variability between log side lengths. The impact of the latter variability source on sample size is shown in **Table 6**. Precisions of ± 5 mm and ± 15 mm were selected to represent ± 0 cm and ± 1 cm when rounded as log length is generally expressed in centimeters. Estimated log sample sizes drop significantly with butt logs removed. These sample sizes only consider manual measurement variability. Harvester calibration sample sizes must include variability in harvester measurements to determine the final log sample size for a specific site. Variability (and hence sample size) may be reduced further by removing other logs with greater manual measurement variability such as those with a high degree of sweep. These logs were not noted during data collection and hence cannot be removed from the dataset.

Estimated log sample sizes to achieve precisions of ± 2 mm, ± 4 mm, and ± 8 mm at a 95 percent confidence probability are

Table 6. ~ *Estimated log sample sizes[a] with or without butt logs to achieve log length precisions of ± 5 and ± 15 mm with a confidence probability of 95% at Capfirco and Brennans.*

	Capfirco		Brennans	
	Precision ± 5 mm	Precision ± 15 mm	Precision ± 5 mm	Precision ± 15 mm
All logs	16	2	41	5
Butt logs removed	8	1	27	3

[a] Sample size = $((2*SD)/E)^2$ where '2' is the approximate t value, SD is the standard deviation from **Table 5**, and E is half of the desired precision.

Table 7. ~ *Estimated log sample sizes[a] using single calliper or diameter tape measurements to achieve diameter precisions of ± 2 mm, ± 4 mm, and ± 8 mm at a 95% confidence probability at Capfirco.*

	Log sample size		
	± 2 mm	± 4 mm	± 8 mm
Callipers	36	9	3
Diameter tape	9	3	1

[a] Sample size = $((2*SD)/E)^2$ where '2' is the approximate t value, SD is the standard deviation from **Table 2**, and E is half of the desired precision.

given in **Table 7**. These precisions were selected to represent typical sawmill scanner precisions, the Swedish forestry standard (90% of harvester diameter measurements within ± 4 mm of manual measurements (Priddle 2005)) and the value recommended by FERIC (75% of harvester diameter measurements within ± 8 mm (FERIC 2004)), respectively. There is no Australian standard for harvester log diameter measurement precision. The substantially greater sample sizes required for single calliper measurements compared with those for diameter tape measurements reflect the greater variability in the calliper measurements.

Value recovery losses, such as those reported by Murphy (2003), are the result of measurement errors from a number of sources, including poor calibration, and the resulting rejection of logs or poor optimisation performance. Rarely is the impact of calibration isolated. In one study that did so, Andersson and Dyson (2002) estimated that for harvesters requiring calibration, length calibration would have increased the number of acceptable logs by up to 23 percent, and diameter calibration would have substantially improved diameter measurement precision.

Harvester operators generally have less incentive to do a thorough diameter calibration as the impact on the operator is negligible except at the minimal acceptable SED. Marshall (2005), however, found in a simulated study of the impact of observed measurement errors on value recovery that diameter errors resulted in greater lost value than length errors.

Recommendations to Minimize Manual Measurement Variability

Equipment damage (e.g., tape stretching and non-parallel calliper arms) and poor operator technique can cause substantial manual measurement errors (Köhl et al. 2006). These error sources should be minimized by annual checking of equipment and operator technique.

Harvester calibration and harvester accuracy studies differ in that calibration needs to reduce variability in both harvester and manual measurements to detect harvester measurement bias whereas harvester accuracy studies can only reduce manual measurement variability, as the goal is to assess harvester measurement performance under normal operating conditions.

Diameter

Inter-instrument variability in manual diameter measurements is mainly caused by logs that are non-circular in cross section. Diameter tape measurements are less affected by log non-circularity and poor measurement technique than single calliper measurements as they have more log contact points. Averaging two calliper measurements at right angles may also reduce measurement variability but at the cost of doubling the number of measurements and increasing the risk of errors when calculating the mean. Diameter tapes are also similar in their operating principles to three-dimensional log scanners used in sawmills. As scanners are often the final arbiters of "correct" log measurements, calibrating with a diameter tape should produce harvester diameter measurements closer to those from a scanner. Diameter tapes are, therefore, recommended for use in harvester accuracy studies and harvester calibration. Logs for harvester calibration should also be as close to circular in cross section as possible and should be elevated from the ground to provide access underneath.

Length

To reduce log length measurement variability in harvester accuracy studies and harvester calibrations where possible, measure the same side as the harvester to remove variability associated with measuring on different sides of irregularly shaped logs. This side can usually be identified by marks made by measuring wheel teeth or by paint sprayed on the log end by the harvester head. Processing stems close to the ground can reduce log rolling and keep the harvester measurement side accessible. Harvester calibrations should also exclude butt logs as they have disproportionately more large length differences.

Conclusion

The assumptions that underpin harvester accuracy studies and harvester calibration – manual log measurements are true and correct and logs are regular in shape – have been found to be incorrect for many of the logs in the stands studied. Although only two stands were studied, observations at other stands suggest that log shape irregularity associated with variability in manual measurements is a widespread phenomenon in radiata pine plantations at clearfall.

The degree of manual measurement variability identified could potentially bias results in harvester accuracy studies to show poorer than actual harvester measuring performance. Harvester calibration would require larger sample sizes to reduce the variability introduced by manual measurements sufficiently to identify and correct harvester measurement bias. A number of simple techniques were identified to reduce manual measurement variability and hence improve the results from harvester accuracy studies and harvester calibration.

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