The Effect of Calibration on the Accuracy of Harvester Measurements

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ABSTRACT

Almost all timber in Ireland is harvested using mechanical harvesting heads. All new harvesters come equipped with computerized measurement systems. The objective of the research reported in this article was to assess the impact of calibration on the accuracy of harvester head measurement systems in Irish forestry conditions. The research was carried out on a site in Co. Cork. The harvester was a Timberjack 1270D with a 762C harvester head and the Timbermatic 300 control and measurement system. The harvester measurement system was assessed on its accuracy in measuring the length and volume of individual stems and logs in 9 check runs of 7 or 8 stems. The harvester head measurements were compared to values obtained by caliper-and-tape measurements. The main point that can be taken from this research is that regular calibration will greatly improve the accuracy of the harvester measurement system.

After calibration, length measurement by the harvester measurement system of individual logs was very accurate, while volume measurement was unsatisfactory for the pulp log assortment. The differences between the harvester measurements and the caliper-and-tape measurements fluctuated greatly, varying from positive to negative differences within a check run, even after calibration. These fluctuations could indicate an inherent problem associated with the design of the calibration procedure, as the positive and negative differences cancel each other out and the calibration, based on mean values, appears to indicate accurate measurements. More work needs to be done on reducing to impact of the roughness and branchiness of smaller dimension logs on the accuracy of diameter and length measurements in Irish conditions.

Keywords: *Harvesters, calibration, measurement accuracy, log length, log volume.*

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INTRODUCTION

Almost all timber in Ireland is harvested using mechanical harvesting systems. Today's harvesters come equipped with computerised measurement systems, which measure the stem during delimbing. A measuring wheel measures the length of the tree (logs) and the delimbing knives measure the stem diameters simultaneously. Every time the stem is cross-cut, the system records the assortment and the volume of the log [15]. If properly managed and maintained, the presence of these measurement systems on harvesters means that an accurate and cost effective measurement resource is available. These computerised measurement systems can generate extremely precise results when installed, programmed and calibrated correctly. Accuracy levels of within ± 2% of real volume have been achieved in Finland on an annual basis [6]. The data from these measurement systems are used as a basis for optimising machine yield and assortment mix, payment of contractors, payment of timber growers and the monitoring of operators [12]. The data are also used in the mill to plan operations and select sawing patterns.

The research presented in this article forms the 3rd phase of an ongoing COFORD (The National Council for Forest Research and Development) funded project based in University College Dublin and carried out in conjunction with Palfab Ltd. sawmill. This research follows work in the first phase, which had the aim to develop a decision support system, incorporating pre-harvest measurement and analysis procedures to provide the timber procurement manager with estimates of the volume, number and diameter class breakdown of log assortments that could potentially be cut from standing timber lots of even-aged, mature Sitka Spruce (*Picea sitchensis* (Bong.) Carr.) [10, 9]. The second phase of the research focused on the decision making process in the mill [2] and had the aim to develop a decision support system for the maximisation of product value recovery in the sawmill.

Given the increased mechanisation of the harvesting operation and the technological advances in harvester head measurement systems in Ireland over the last decade [3], it was decided that the third phase of the research should investigate the impact of calibration on the accuracy of harvester head measurements.

BACKGROUND

Over the last 3 decades, the technological development of harvesting operations has been innovative and rapid. There have also been revolutionary developments in communications and information technology. These developments have led to a definite trend towards increased integration of harvesting, log conversion and marketing operations [11]. The sawmill can use this timber volume, length and diameter information from the harvesters to get a more detailed account of the timber harvested and the various assortments cut. Möller and Sondell [8] suggested that timber payment based on harvester measurement could speed up transactions, improve control of the wood flow and make reception at the mill more efficient. They also stated that it is quite likely that we are on the threshold of a new way of working, in which measuring by harvester would be a key to improved efficiency and cost-effectiveness in the wood flow.

Provided the measurement systems are set-up and calibrated as per design specifications, the harvesters can produce extremely accurate results. Requirements in Finland stipulate that volume estimate by the harvester must be within ± 4% of the true stand volume. The systems there are now achieving, on an annual basis, accuracy levels of within ± 2% of the true stand volumes [6]. Studies on harvesting heads by the British Forestry Commission (BFC) reported similar accuracy levels to those recorded in Scandinavia [1]. In Ireland a study carried out in 2001 found total volume measurement accuracy levels of 6.7% for a clearfell site and 5.3% for a thinning site [13].

The successful use of the measurement systems is dependent on regular and systematic calibration and maintenance. Calibration is the checking, and if necessary correcting, of harvester measurement systems, by measuring the same logs with the harvester and then with a tape and calipers, to ensure accurate production data. Calibration checks and systems are commonplace in all Scandinavian countries. The aim of the research reported in this article was to assess the impact of calibration on the accuracy of harvester head measurements in Irish forestry conditions. In order to achieve this aim, a detailed analysis of the accuracy of the (calibrated) harvester measurement system when measuring the length and volume of individual stems and logs was carried out.

MATERIAL AND METHODS

The data used in this study were collected in Guagan Barra Forest, situated circa 5 km outside Ballingeary in Co. Cork. Like all production forests owned by Coillte Teoranta (the Irish Forestry Board), this forest has been intensively managed, resulting in very uniform, even-aged stands. The stand used in this study extended to 25 ha and consisted of 42 year-old Sitka spruce trees, and a pre-harvest inventory found a mean dbh of 23 cm (ranging from 11 cm to 42 cm), a mean tree height of 21 m and a mean (over-bark) merchantable tree volume of 0.47 m^3. The inventory also showed that the stocking was 1326 stems per ha, resulting in an estimate of the total harvest volume on the site of 15,581 m^3. A Timberjack 1270D with a 762C harvesting head and the Timbermatic 300 measuring and control system was used. The harvesting head has a maximum cutting diameter of 65 cm. After felling the tree, the machine delimbs, measures and cross-cuts the stem in one operation. The measuring and control system will identify suitable logs, based on the diameter and length specifications for each assortment category that have been entered in the control system. The operator has to accept or reject each cross-cutting suggestion. This machine was working normal operating hours, circa 10 hours per day. At regular intervals, approximately every 5 hours, a calibration check was carried out. Seven or eight stems were processed by the machine and the resulting logs were presented in a way that facilitated the manual measurement of lengths and diameters. At the same time, the length and volume data for these logs as collected by the harvester were downloaded from the on-board computer. As the manual measurements were carried out and the resulting data were compared with the harvester measurements (using a laptop computer), the harvester continued operating. As soon as the calibration check was completed, and the results indicated the need for calibration, this was carried out. The calibration consisted of the inputting of the manually collected length and volume measurements for the 7 or 8 stems into the on-board computer of the harvester, as specified in the calibration procedures of the manufacturer. The on-board computer then calibrated its measuring routines. The actual harvester calibration and measurement software was not accessible to the research team.

Three different types of measuring devices were used in this research to calculate the lengths and volumes of logs. These were the calipers, the logger tape and the Timberjack measurement system. The measurement system was being assessed on its accuracy in measuring the length (m) and volume (m^3) of saw logs and pulp logs. The 9 calibration check runs resulted in data on 67 stems that were crosscut into 134 saw logs and 154 pulp logs. The saw logs included 4.90 m (with a minimum small end diameter (sed) of 14 cm) and 3.10 m (minimum sed of 14 cm) length logs while the pulp logs were all of 2.90 m length (minimum sed of 7 cm).

For manual volume measurements, which followed the recommended calibration procedures as outlined by the machine manufacturer, the logs were, starting at the butt end, divided into 1 m sections and the diameter of each was measured twice, perpendicular to each other, in the middle of each section (i.e. at 0.5 m, 1.5 m and so on). On the final section of each log, which was shorter than a meter, the measuring point was located in the middle of its actual length. The presence of a whorl at the measuring point resulted in moving the point up along the log to where the diameter better represented the relevant section. The volume of each section is calculated based on the mid-diameter, i.e. as a cylinder with a diameter equal to the mean of the two measurements. The lengths and volumes of the sections were then added together to obtain the total length and volume for the log. This procedure closely mimics the method used by the harvester measurement system, except for its much more frequent diameter measurements (at 5 cm intervals), resulting in many, short cylinders. The recommended lower frequency of diameter measurements in the manual system has to be seen in the light of the time and cost associated with the calibration process.

The caliper-and-tape measurements were taken as the true or correct measurements and the harvester measurements were compared against these. If the differences between the volume measurements from the harvester measurement system and the caliper-and-tape system were greater than 5% for the saw logs in the check run or greater than 7% for the pulp logs, calibration would be carried out. These levels of accuracy were selected based on sawmill requirements, on other Irish calibration studies and on calibration checks that had been carried out in preliminary investigations. If some external factor (operator error, stem(s) judged exceptionally rough or crooked during the manual measurement process) was identified that might have caused the differences to be greater than the 5% and/or 7% limits, no calibration was carried out until the next scheduled check run indicated that the difference(s) remained outside the limit(s). As a result of these specifications, calibrations were carried out as follows:

- Calibrated after check run 1 because of saw log and pulp log differences were greater than 5% and 7% respectively.
- Calibrated after check run 2 to investigate if calibration could reduce differences further when already with in the 5% and 7% limits.
- Not calibrated after check run 3 as both saw and pulp log differences were within the limits.
- Not calibrated after check run 4 even though the differences for both saw logs and pulp logs were outside the respective limits, but these differences were judged to have been caused by operator error. Examples of the rare occurrences of operator error were: forgetting to reset the length measurement to zero after having removed an unmerchantable section or after losing grip on the stem.
- Calibrated after check run 5 because pulp log difference remained greater than 7%.
- Not calibrated after check run 6 as both saw and pulp log differences were within the limits.
- Not calibrated after check run 7 as both saw and pulp log differences were within the limits.
- Not calibrated after check run 8 as both saw and pulp log differences were within the limits.
- Not calibrated after check run 9 even though the pulp log difference was > 7%, because no further observations were carried out.

The statistical analysis of the differences in length and volume measurements of the saw logs and pulp logs in each check run was carried out using a Paired Two Sample t-Test on the means of the data from the two measurement systems at 95% confidence level (P>0.05). Although the two sub-populations (saw logs and pulp logs) are clearly dependent, together making up the tree population, this did not invalidate the statistical comparisons of the two measuring systems carried out on each sub-population separately. However, care should be taken in any comparisons between the results for the saw log and pulp log samples.

RESULTS

The calibrations after check runs 1 and 2 clearly reduced the differences in volume measurements for both the saw and pulp logs (Figure 1). The total harvester log volume and the total caliper-and-tape log volume in check run 3 were equal, while there was a difference of less than 2% between the harvester pulp volume and the caliper-and-tape pulp volume in this check run. The least accurate check run was the first one where no calibration had yet been carried out.

The ranges of differences between harvester measurements and tape-and-caliper measurements of log length and log volume for all logs combined in a stem and for individual saw log and pulp log values are presented in Table 1. Total stem length differences are small, in all cases within ± 3%. Total volume differences range between –7.5 and +16%, with large fluctuations between check runs. The individual saw log length differences ranged generally between –1 and +2%, with single values at –8.5 and –9.5%. For pulp logs these differences ranged generally between ±3%, with single differences at –5 and +7%. The greatest differences were found for the individual log volumes, with saw log differences ranging between – 7.5 and 9% and pulp log differences between –22 and +22%. No clear effect of calibration can be detected on these difference ranges for runs after calibration and those not preceded by calibration.

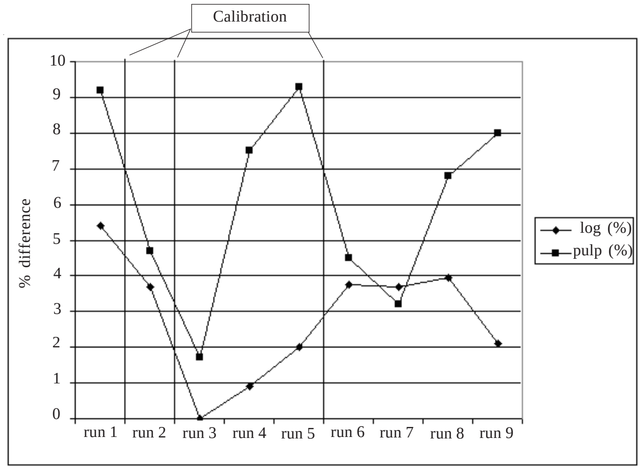

Figure 1. Effect of calibration on harvester measurement accuracy of volume over the 9 check runs, expressed as the percent difference with the caliper-and-tape measurement.

Table 1. Summary of number of logs in each run, their mean and median mid-diameter, and the total stem and individual log length and volume difference ranges.

		Run								
		1	2	3	4	5	6	7	8	9
Stem	Number of stems	8	8	8	8	7	7	7	7	7
	Range of stem length differences %)	-1/+1	-1/+1	-2.5/+1	-1/+1	-1/+1	-1/+1	-1/+1	-1/+1	-1/+1
	Range of stem volume differences %)	+3/+9	0/+6	-8/+4.5	+1/+13	+2/+12	0/+7	-.5/+6.5	+1/+8	-.5/+16
Sawlog 4.9 m	number of logs	19	17	10	8	9	17	16	9	10
	mean diameter (cm)	22.7	24.1	23.1	20.6	20.1	26.3	25.0	26.7	20.7
	median diameter (cm)	22.1	23.8	23.4	19.4	20.0	27.0	24.3	25.0	21.1
	range of log length differences (%)	-1/+1	-1/+4	-8/+2	0/+1	-1/0	0/-1	0/-10	0/-1	-1/+1
	range of log volume differences (%)	-11/+2	-3.5/+9	-7.5/+7.5	1.5/+4	-5/+6.5	-2/+10	-5/+12	-4/+8	-4/+5
Sawlog 3.1 m	number of logs	3	3	0	0	2	2	4	5	2
	mean diameter (cm)	16.9	17.4			17.1	20.4	19.7	17.2	15.9
	median diameter (cm)	16.2	17.2			17.1	20.4	19.8	16.6	15.9
	range of log length differences (%)	0/+1	0/+1			0.0	-1/0	0/+1	0/+1	0/0
	range of log volume differences (%)	-3/0	-8/+5			-3/+4.5	-3/-8	-7/0	-14/+5	-5/0
Pulplog 2.9 m	number of logs	15	13	18	23	16	13	16	20	20
	mean diameter (cm)	13.0	14.0	13.2	14.0	12.4	15.0	15.2	12.6	12.4
	median diameter (cm)	13.4	14.0	12.8	13.0	12.6	15.0	14.9	12.4	12.0
	range of log length differences (%)	-2/+2	-2/+2	-5/+7	-3.5/+1	-1/+3	-2/+2	-1/+1	-2/+5	-1/+1
	range of log volume differences (%)	+3/+16	-22/+10	-15/+16	-9/+22	-5/+20	-2/+17	-2/+13	0/+15.5	-8/+21
Calibration (after the run)		**Yes**	**Yes**	**No**	**No**	**Yes**	**No**	**No**	**No**	**No**

Statistical Analysis of the Length and Volume Data

Saw log length

The analysis of the saw log lengths showed that the means of the harvester and tape measurements in each check run were similar with less than a ±4 cm difference in any run (Tables 2 and 3). No 3.10 m logs were cut during runs 3 and 4. The statistical analysis showed that there were significant length differences for the 4.90 m length logs at the 95% confidence level in two of the check runs (6 and 8). In both cases the harvester length values were significantly higher than those obtained using the tape, even though the actual differences between the means were only 1 and 4 cm, respectively and the individual log lengths of 105 of the 115 logs were within the allowable range. For the 3.10 m length logs, were there was only a total of 21 logs in 7 runs, the statistical analysis showed that there was a significant length difference at the 95% confidence level in check run 8.

Saw log volumes

The analysis of the (over-bark) saw log volumes showed that the differences between the harvester means and the caliper-and-tape means for the 4.90 m logs in nine check runs were not greater than 0.012m^3 in any run (Tables 4). The statistical analysis showed that there were significant volume differences at the 95% confidence level in three of the check runs (1, 2, and 6). In all of these cases the harvester volume values were significantly lower than those obtained using the caliper and tape. The differences between the harvester means and the caliper-and-tape means for the 3.10 m logs in nine check runs were not greater than 0.006m^3 in any run (Tables 5). No significant differences were found.

Pulp log length

The means of the harvester and tape measurements in each check run were similar with less than a ±3 cm difference

Table 2. Statistical comparisons of 4.90 m saw log length in the nine check runs.

Check run	No. of Samples	Harvester (m) Mean	Harvester (m) Variance	Tape (m) Mean	Tape (m) Variance	t Critical	t Stat
1	19	4.93	0.00009	4.93	0.00087	2.10	0.35
2	17	4.93	0.00006	4.93	0.00042	2.12	0.11
3	10	4.93	0.00007	4.89	0.01651	2.26	1.00
4	8	4.94	0.00003	4.93	0.00037	2.34	0.45
5	9	4.93	0.00005	4.92	0.00049	2.31	1.11
6	17	4.93	0.00007	4.92	0.00026	2.12	4.74*
7	16	4.93	0.00007	4.89	0.01127	2.13	1.39
8	9	4.93	0,00007	4.89	0.00063	2.31	4.26*
9	10	4.93	0.00007	4.92	0.00046	2.26	1.10

* significant at 95% confidence

Table 3. Statistical comparisons of 3.10 m saw log lengths in the nine check runs.

Check run	No of Samples	Harvester (m) Mean	Harvester (m) Variance	Tape (m) Mean	Tape (m) Variance	t Ctitical	t Stat
1	3	3.10	0.00002	3.08	0.00040	4.30	17.3
2	3	3.10	0.00002	3.07	0.0005	4.30	2.00
3	0						
4	0						
5	2	3.12	0.00005	3.11	0.00000	12.71	1.00
6	2	3.10	0.00000	3.12	0.00005	12.71	3.00
7	4	3.11	0.00009	3.11	0.00083	3.18	0.93
8	5	3.11	0.00003	3.09	0.00003	2.78	3.21*
9	2	3.11	0.00005	3.11	0.00020	12.71	1.00

* significant at 95% confidence

Table 4. Statistical comparisons of 4.90 m saw log volume in the nine check runs.

Check run	No. of Samples	Harvester (m) Mean	Harvester (m) Variance	Caliper & Tape (m^3) Mean	Caliper & Tape (m^3) Variance	t Critical	t Stat
1	19	0.194	0.0054	0.206	0.0057	2.10	6.54*
2	17	0.224	0.0070	0.233	0.0078	2.12	3.35*
3	10	0.213	0.0068	0.213	0.0065	2.26	2.26
4	8	0.168	0.0051	0.170	0.0049	2.34	1.27
5	9	0.155	0.0018	0.158	0.0021	2.31	1.75
6	17	0.265	0.0079	0.275	0.0089	2.12	3.48*
7	16	0.242	0.0114	0.251	0.0145	2.13	2.06
8	9	0.282	0.0240	0.293	0.0296	2.31	1.75
9	10	0.166	0.0023	0.170	0.0028	2.26	1.98

* significant at 95% confidence

Table 5. Statistical comparisons of 3.10 m saw log volumes in the nine check runs.

Check run	No. of Samples	Harvester (m) Mean	Harvester (m) Variance	Caliper & Tape (m^3) Mean	Caliper & Tape (m^3) Variance	t Critical	t Stat
1	3	0.069	0.0003	0.070	0.0003	4.30	1.73
2	3	0.071	0.0002	0.073	0.0001	4.30	0.67
3	0						
4	0						
5	2	0.072	0.0001	0.071	<0.0001	12.71	0.20
6	2	0.098	0.0013	0.104	0.0019	12.71	1.44
7	4	0.092	0.0003	0.096	0.0003	3.18	2.65
8	5	0.069	0.0002	0.073	0.0002	2.78	1.50
9	2	0.060	<0.0001	0.061	<0.0001	12.71	1.00

* significant at 95% confidence

in any run (Table 6). The variances of the means were small, especially those for the harvester data. The statistical analysis showed that there were significant length differences at the 95% confidence level in four of the check runs (4, 5, 6, and 9). In all of these cases the harvester length values were significantly higher than those obtained using the tape. However, the differences between the means were not greater than 2 cm.

Pulp log volume

The pulp log (over-bark) volume analysis showed that the differences between the harvester means and the caliper-and-tape means were small, with no more than a 0.004 m^3 difference in any check run (Table 7). The variances were also small. There were significant volume differences at the 95% confidence level in eight of the check runs (1, 2, 4, 5, 6, 7, 8 and 9). In all of these cases the harvester volume values were significantly lower than those obtained using the caliper and tape.

DISCUSSION

The research detailed in this article was part of a larger project with the objective to develop a decision support system for the sawmill industry in which the pre-harvest inventory results and cross-cutting decisions in the forest are integrated with the sawing decisions in the mill to create an optimal 3-dimensional conversion process [9]. Faaland and Briggs [5] were the first to analyse the two activities of crosscutting the tree and of sawing the resulting logs into lumber together. Reinders [14] developed a decision support system integrating these two decisions and activities into a 3-D optimisation procedure.

The main objective of the research presented in this article was directed to investigate the impact of calibration on the accuracy of harvester head measurements. An analysis was carried out of the accuracy of an harvester measurement system when measuring length and volume

Table 6. Statistical comparisons of 2.90 m pulp log length in the nine check runs.

Check run	No. of Samples	Harvester (m) Mean	Harvester (m) Variance	Tape (m) Mean	Tape (m) Variance	t Critical	t Stat
1	15	2.90	1.24E-05	2.90	0.00107	2.145	0.307
2	13	2.91	7.31E-05	2.90	0.00059	2.179	1.298
3	18	2.90	4.97E-05	2.88	0.00561	2.110	1.353
4	23	2.91	0.00038	2.90	0.00022	2.074	2.501*
5	16	2.90	3.79E-15	2.88	0.00064	2.132	2.859*
6	13	2.91	5.90E-05	2.89	0.00031	2.179	4.153*
7	16	2.91	8.96E-05	2.90	0.00042	2.132	1.695
8	20	2.91	3.03E-05	2.90	0.00160	2.093	0.626
9	20	2.91	4.50E-05	2.89	0.00032	2.093	3.479*

* significant at 95% confidence

Table 7. Statistical comparisons of 2.90 m pulp log volume in the nine check runs.

Check run	No. of Samples	Harvester (m^3) Mean	Harvester (m^3) Variance	Caliper & Tape (m^3) Mean	Caliper & Tape (m^3) Variance	t Critical	t Stat
1	15	0.035	0.00013	0.039	0.00015	2.145	8.744*
2	13	0.044	0.00027	0.046	0.00028	2.179	3.895*
3	18	0.040	0.00042	0.041	0.00035	2.110	0.817
4	23	0.045	0.00116	0.049	0.00130	2.074	4.528*
5	16	0.032	0.00012	0.036	0.00012	2.132	6.656*
6	13	0.051	0.00042	0.053	0.00043	2.179	3.349*
7	16	0.054	0.00077	0.055	0.00073	2.132	3.090*
8	20	0.035	0.00019	0.037	0.00021	2.093	6.962*
9	20	0.033	0.00013	0.036	0.00013	2.093	5.289*

* significant at 95% confidence

of individual stems and logs. Based on the nine check runs, it was found that calibration reduced the percentage difference between the harvester measurement and the caliper-and-tape measurement for pulp logs in all three cases and for saw log in two out of the three calibrations, while without calibration the percentage difference increased in eight out of 10 cases. This trend indicates the importance of calibration on a regular basis. The determination of the optimal calibration frequency (which will be dependent on both stand and harvesting head characteristics) requires further research in a variety of stands. The harvester measurements were more accurate for the saw log categories than for the pulp log category. A similar finding was obtained in a study by PTR [12]. A reason for the lower accuracy level for the pulp logs could be that this assortment is predominantly cut from the top part of a stem which has the most branches and can be extremely rough in Irish grown Sitka spruce [7]. This roughness will cause problems with the length and diameter measurements of the harvester, as both are dependent on contact between components of the harvesting head (i.e. the length measurement wheel and the delimbing knives, respectively) with the log. The crookedness and frequent presence of branch stubs on pulp logs will cause the recording of incorrect values for both length and diameter by the harvester, while the manual system is able to deal with these factors.

In the analysis of the percentage difference in length between the harvester measurements and the caliper-and-tape measurements for all the logs in each stem, it was found that the harvester measurements were very accurate. The harvester measurement system determined the length of only 2 stems (out of a total of 67 for all check runs) with a difference greater than ± 2% compared to the tape measurement. In the analysis of the percentage volume difference between the harvester measurements and the caliper-and-tape measurements for all the logs in each stem, it was found that the accuracy of the harvester varied considerably.

The breakdown of results of the 9 check runs into those for the saw and pulp log categories resulted in considerable differences between individual log volumes as determined by the harvester and the caliper-and-tape measurement systems, as illustrated by the range information in Table 1. These differences fluctuated greatly, varying from positive to negative differences within a check run; and, while after calibration the size of the mean difference between the caliper-and-tape and harvester measurements within a check run was reduced, the fluctuations were still quite erratic [4]. These fluctuations between positive and negative differences could indicate an inherent problem associated with the design of the calibration procedure as recommended by the machine manufacturer and as used in this study, as the positive and negative differences within each log category cancel each other out and the calibration, based on mean values, appears to indicate accurate measurements.

The length measurements by the harvester for both the saw and pulp log categories resulted in greater or equal mean values than those obtained by the tape measurements for all runs (except for the 2 logs in the 3.10 m category in run 5), while for volume measurements the results were the exact opposite with greater or equal mean values for the caliper-and-tape measurements (except for the two 3.10 m logs in run 5). As all diameters were measured over-bark, the only logical explanation for these contradicting results is that the diameter measurements by the harvester produced smaller values than the caliper measurements. As it was not possible to record the individual harvester diameter measurement values used in the volume calculations, it was not feasible to check this hypothesis. The consistent trend in the results, no matter if calibration had taken place or not before the check runs, and given the general uniformity of the stand, indicates that the calibration process, as carried out by the harvester control and measurement system, did not eliminate the length and diameter discrepancies but improved the accuracy of the volume measurements. When the differences between the harvester and caliper-and-tape length and volume measurements for the saw log category were statistically analysed, only a small proportion of check runs resulted in significant differences, indicating that, even though the trends were quite obvious, the actual differences were generally not great enough, and/or the variances were too great, to reach statistical significance. When the differences between the harvester and caliper-and-tape length and volume measurements for the pulp log category were statistically analysed, the majority of check runs showed significant differences. The actual differences between the harvester and caliper-and-tape means for pulp log length and volume were however extremely small, indicating the potential disparity between the statistical significances of research results and the operational relevance of these findings.

CONCLUSIONS

The research work presented in this article has highlighted the importance of calibration procedures. If as a result of calibration procedures, harvesters can produce accurate reports of what types of logs will be entering the mill yard on a weekly basis, the procurement manager can liaise with the sawmill manager and the marketing manager, thereby creating the opportunity to optimize the use of the raw material, satisfying customer demands, and maximizing profits. Based on the research carried out and the results obtained, the following conclusions can be drawn. Length estimates obtained by the harvester measurement system were compatible with the results obtained with the tape measurement system for the two limited assortment categories. Volume estimates obtained by the harvester measurement system for the saw log category were relatively accurate, with the differences between harvester and caliper-and-tape measurements in 8 out of the 9 check runs within the ±5% limits. However, volume estimates for the pulp log category were unacceptable, with the differences in 4 out of the 9 check runs outside of the ±7% limits. The mathematical foundation of the calibration procedure, where positive and negative differences can cancel each other out, should be investigated. The resulting mean difference, close to zero, could give a false and misleading impression of the accuracy of a measurement system that produces individual logs that can have length and/or diameter dimensions that are outside a sawmill's product specifications, resulting, in the removal of the excess material to waste or low value products, the downsizing of the log to the next shorter and lower value product category, or the rejection of the log completely. In the case of pulp logs, where the total volume in the lot determines the value, this problem with the calibration process is less relevant.

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