DESIGNING VALUE CHAIN IMPROVEMENTS FOR AN EASTERN OREGON POPLAR PLANTATION USING TERRESTRIAL LASER SCANNING TECHNOLOGY

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ABSTRACT

GreenWood Resources manages 12,000 hectares of short-rotation (~12 years) poplar plantations in eastern Oregon and Washington. Trees are pruned to a height of approximately 7.5 m to produce a knot-free sheath surrounding a knotty core. The current harvesting and transport system utilizes a feller-buncher, tree-length grapple skidder extraction to roadside, a static delimber/slasher (or processor/delimber), and long length (~ 17 m) off-highway trucking to a centrally-located mill yard. The mill, which is owned by GreenWood Resources' North American Tree Farm Fund (GTFF), produces chips from the upper stem segments and predominantly appearance grade lumber and pallet wood from the lower pruned stem segments.

In summer 2010 sixty forest inventory plots in three stands were measured using a terrestrial laser scanning (TLS) system. A subset of inventory plots (4 to 8) from each stand were felled then manually measured before the stems were extracted, bucked, and transported to the mill. The log-length logs were then debarked, scanned and bucked into shorter lengths (2.5 to 3.8 m) before sawing. Bucking was based on the lumber and value that could be extracted from each short log.

- Based on the data that has been gathered and preliminary analyses of three of the sixty plots, we have been able to:
- determine mill-door values for poplar logs of specific lengths, diameters and maximum sweep tolerances
- show that TLS is not as accurate as mill scanning equipment but does show promise as a pre-harvest inventory tool for determining stand value and log product yields
- establish that the time to gather detailed scan data was about half an hour per plot demonstrate how TLS data and optimal bucking could be used to quantify value chain improvements such as adding a veneer line to the mill and reconfiguring the mill's infeed scanning system.

Keywords: terrestrial laser scanning, hybrid poplar, optimal bucking, value chain

INTRODUCTION

The main component of GreenWood Resources' North American Tree Farm Fund (GTFF) is the Boardman Tree Farm (BTF), a hybrid poplar tree farm located near Boardman, Oregon just south of the Columbia River in eastern Oregon. In the summer of 2010 a terrestrial laser scanning (TLS) trial was initiated with a number of goals in mind. One of these goals was to determine if TLS technology could be used to help GreenWood Resources identify and design value chain improvements for their operations.

GTFF contains approximately 10 thousand hectares of hybrid poplar trees. Surrounding land is primarily utilized for agricultural purposes. The area is dry and hot during the summer and dry and cold during the winter. The area is also characterized by windy conditions which result in many trees having lean and sinuosity in the direction of the prevailing winds. The two-dimensional shape of the stems in cross section is elliptical as opposed to circular due to wind loading.. BTF is separated into various age classes and stocking densities on rectangular parcels representing individual stands. Each stand, approximately 70 hectares in size, contains hybrid poplar of the same age and at a particular stocking density. GreenWood Resources grows and harvests trees on a 12 year rotation. Between ages 2 to 5 years trees are pruned in several lifts to a height of approximately 7.5 meters to produce a knot free sheath surrounding a knotty core a. At maturity trees are harvested mechanically by a feller buncher. A grapple skidder is then used for tree length extraction to the roadside where trees are bucked to approximately 17 meters and delimbed by a static delimber/slasher (or processor/delimber). The 17 meter logs are then transported to a mill that is centrally located at BTF and processes all harvested raw timber. Each tree usually yields appearance grade lumber and pallet wood from the lower part of the stem, and chips from the upper parts of the stem that are too small to produce lumber.

Good metrics of the quantity, quality and location of timber resources within each stand are essential for ensuring that wastage is minimized, harvest and volume growth increments are balanced, log products are optimally matched to markets, and the value of the forest is maximized at the time of harvest. Forest owners around the world are evaluating new approaches for obtaining these metrics with the goals of increasing their accuracy and reducing their data gathering costs. Emerging technologies include satellite imagery (Tomppo et al. 1999), harvester data collection and data mining (Murphy et al. 2006), airborne laser scanning (Reutebuch et al. 2005), and TLS (Bienert et al. 2007, Keane 2007).

TLS, which allows production of individual 3D stem profiles, is being used operationally in Ireland to assess stand value and estimate log product yields. It has been studied in a number of trials worldwide. In Sitka Spruce in Ireland, in Douglas-fir in Oregon, USA, and in radiata pine in Australia (e.g. Keane 2007, Murphy 2008, Murphy and Acuna 2010, Murphy et al. 2010) timber was measured with TLS, manually, and with a mechanical harvester. The stem diameters, volume and value recovery estimates resulting from each method were compared. These trials highlighted the potential utility of TLS technology and the conditions under which it might work best. Teobaldelli et al. (2008) have used TLS to measure stem diameters at height of 1.37 or breast height (DBH) (sample of 21 trees) and upper stem diameters (sample of 3 trees) in 14-year old intensively managed poplar plantations in Italy. Average TLS diameters were reported to be within one centimeter of manually measured diameters. Antonarakis (2011) compared manual

and TLS measured DBH's in complex riparian poplar forests in France and found a mean bias of less than a half a centimeter (~1.5%).

Siefert et al. (2010) have simulated lumber recovery based on TLS scans of pine stems in South Africa. As far as we have been able to determine, the relationships between TLS measurements and actual mill scan measurements, with respect to volume and value recovery estimation, have not been investigated for poplar stands. Nor has the ability of TLS to accurately scale logs based on log sweep been assessed.

Here we describe the methods we used to compare TLS and mill scan measurements. We also present preliminary findings, based on a subset of our measured stands, plots and stems, and show how TLS measurements can be used to identify and design value chain improvements for GreenWood Resources operations. It should be noted that we are at the early stages of our analyses and that our conclusions may change once all stands, plots and stems have been analyzed.

MATERIALS AND METHODS

In the summer of 2010, when the poplars were in full foliage, each of three stands - low, medium and high stocking densities - was sampled systematically with a random starting point for each stand. The low stocked stand contained 360 stems per hectare (spha), the medium stocked stand contained 550 spha and the highly stocked stand contained 725 spha. Twenty equally spaced circular plots each of 10 meter radius - approximately 3% of a hectare - were located in each of the three stands. Each plot center was permanently marked and all trees in each of the sixty plots numbered and measured DBH. Five standing trees per plot were manually measured for height with an Impulse laser rangefinder .

A Trimble FX laser scanner was used to collect standing tree TLS measurements from two locations within each plot if tree(s) within the plot radius were occluded. The primary scan occurred at the center of the plot and the secondary scan approximately five meters from the plot center. Time to set up the scanner and take two scans per plot was usually less than half an hour.

Random subsamples of plots were selected for felling and detailed manual and mill measurements. There were 8, 4 and 6 plots randomly chosen from each of the stands containing 360, 550 and 725 spha, respectively. Each tree in the randomly selected plots was mechanically felled, delimbed and then manually tagged on the butt for identification at the mill. The subsampled plots yielded approximately 70 trees from each of the 360 and 550 spha stocked stands, and 160 from the 725 spha stocked stand, for a total of 300 trees that were transported to the mill.

From the 300 trees to be transported to the mill, fifty trees from each stocking level were manually measured using calipers for diameter over and under bark (bark was removed with a axe) to determine bark thickness at 0 meters, 1.3 meters (DBH), 3 meters, 6 meters, and then at 3 meter intervals up to a 50 mm top. Trees from the sub-sampled plots were then transported to the mill and bucked at about 17 m (the maximum length for the mill's log scanner. The bottom 17 m

stem section was scanned using a Nelson Brothers Equipment scanner (NBE) for diameter and sweep with the bark on. The trees were then rescanned after debarking and optimally bucked to sawlog lengths (8 – 12 ft or 2.6 – 3.8 m). The bucked logs were then sawn in the mill and lumber recovery recorded. Lumber recovery and grade data was combined with lumber prices and chip prices and mill operating costs to determine return-to-log mill-door values for logs of different lengths, dimensions and sweep classes.

The Trimble FX scans were processed using software developed by Treemetrics Ltd. (Ireland) to automatically detect tree locations and stem profiles within each plot. TLS can not "see" through stems, branches or leafy vegetation. In the upper portions of the stem, a taper function was used by the Treemetrics software to automatically estimate diameters for stem sections that could not be seen. Based on the detailed TLS stem profiles, each stem was optimally bucked using VALMAX Optimizer simulation software (developed by the first author). The return-to-log prices were used in VALMAX to provide tree and plot estimates of total recoverable volume and log product yields. TLS based tree, value and product yield estimates could then be compared with manual and mill scan measurements.

In the summer of 2011 we will retake TLS and manual measurements on the remaining plots in all three stands. The purpose of rescanning is to compare annual growth predictions based on TLS and manual measurement methods.

PRELIMINARY RESULTS

The following results are based on trees from three of the 20 plots within one of the three stands; the high stocked stand. The results should be considered as preliminary.

Accuracy of TLS as a pre-harvest inventory tool

We compared underbark diameter measurements at various heights (butt, breast height, 6 m, 9 m, 15 m and 24 m) on the tree for Plots 2, 3 and 6 combined. Overbark TLS measurements were converted to underbark measurements through use of a bark thickness equation. Figure 1 shows the average diameter differences for the TLS, NBE and manual measurement methods. A positive difference means that the average diameter for the first method was greater than for the second method; e.g. the average butt diameter measured by TLS was greater than the average butt diameter measured by the NBE scanner in the mill. There were no NBE data at the 24 meter height because the maximum length of stem that could be scanned by the NBE scanner was about 17 m.
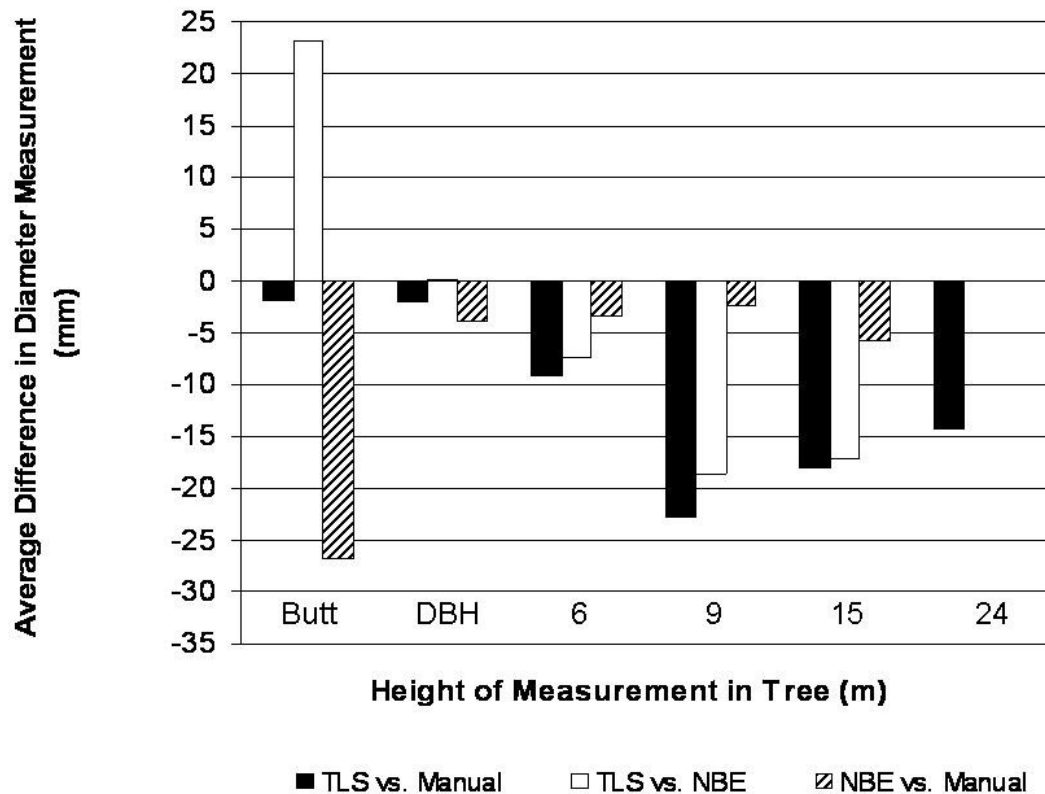
Figure 1: Comparison of average difference in diameter measurement between TLS, NBE and manual methods. A positive difference means that the average diameter for the first method was greater than for the second method; e.g. the average butt diameter measured by TLS was greater than the average butt diameter measured by the NBE scanner in the mill.

At the butt, both TLS and NBE measurement methods underestimated the manual measurements; the underestimate being slightly larger for the NBE method. Accurately measuring diameter at the butt for stems with elliptical, rather than circular, trunks was problematical for the TLS method. The Treemetrics software that is integral to the TLS method we tested assumes that tree cross sections are circular. This is not a good assumption for the wind-influenced poplar stands we were working in. For example, one of the stems had a 40 mm difference in diameter at the butt when scanned from two different directions. We note that the same tree had a 40 mm difference in DBH when scanned from two directions as well.

At breast height the average difference between TLS diameter measurements and diameter measurements taken by the other two methods was lower than those taken at any other height position on the stem. This indicates that TLS measurement is fairly accurate at breast height when compared to the NBE and manual methods; average differences being 0 and -2 mm respectively (0 and 0.8%).

At heights above breast height the accuracy of diameter measurements taken by TLS tends to decrease. At the 6 meter height the average difference in diameter measurement was less than 10 mm between TLS and the NBE and manual methods. The largest average difference in diameter measurement between TLS and the other two measurement methods was at the 9 meter height; an average underestimate of about -20 mm. As noted above the poplar stand had been pruned to about 7.5 m. A heavy whorl of limbs, with some nodal swelling, tended to form above the top of the pruned zone. The Treemetrics software used with the TLS system follows a similar convention to that used on mechanized tree harvesters; namely, diameters further up the stem from a given measurement point can either remain constant or decrease, they can not increase. This convention may have been the reason for the larger difference (underestimate) between TLS measurements and the manual and NBE measurements at the 9 m height.

The average difference in diameter measurement was also large at the 15 meter height, although not as large as at the 9 meter height (an average underestimate of about -17 mm).

There was no NBE data at the 24 meter height; however, the average difference in diameter measurement between TLS and manual methods was assessed; the difference being less than -15 mm at this height. It is unlikely that the scanner was providing actual measurements of the stem at this height in the foliated condition for the hybrid poplar. It is likely that the taper function automatically provided this information; hence the improvement in measurement accuracy.

From breast height to the 24 meter stem height the average TLS diameter measurement was lower than the average NBE and manual diameter measurements. The NBE measurement closely followed the manual measurement at all points measured on the stem. The overall trend indicates that TLS may underestimate poplar stand volume that could be delivered to the mill. Murphy and Acuna (2010) also noted this trend in Sitka spruce, Douglas-fir and radiata pine stands.

Mill door values based on maximum sweep class

The trend in mill-door values was determined by examining the relationship between log value ($ per m^3), log dimensions (length and diameter) and sweep ratio (Figure 2). Small end diameter (SED) and sweep were found to be the key variables affecting value on a per cubic meter basis. Sweep can be defined as the ratio of SED over the center-line displacement, so when the sweep ratio is low for a particular log it means that the maximum center-line displacement is large relative to the SED of that log. Simply put, the lower the sweep ratio the more sweep can be found in that particular log. As expected, the relationship between mill value and SED was positive (bigger logs have higher value per m^3) and between mill value and sweep was negative (the greater the curvature of the log, the less value was extracted from it) no matter what the SED class. The range of values for each SED class was between $7 per m^3 and $8 per m^3, indicating that the trend for sweep was similar for each SED class.
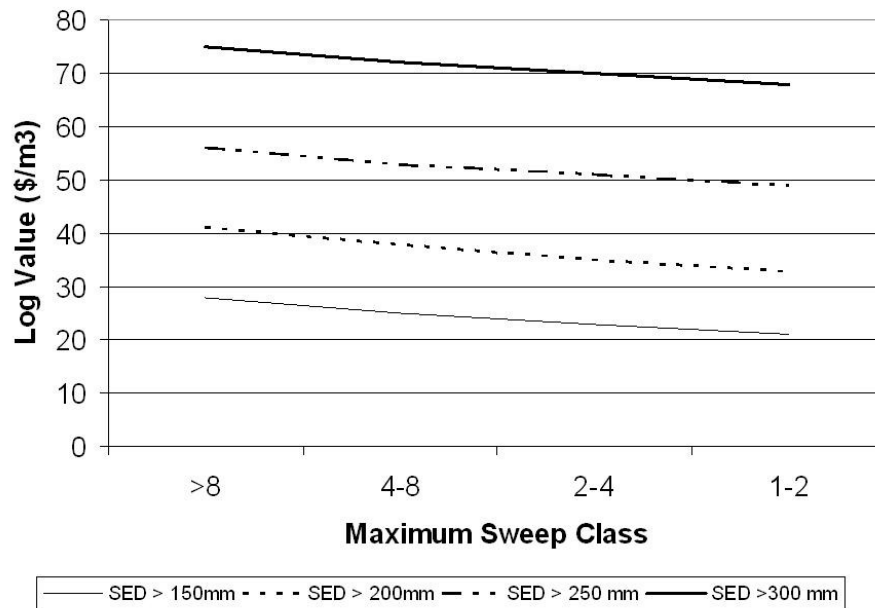
Figure 2: Relationship between log value ($/m^3) and maximum sweep class; the higher the sweep class number the straighter the log.

Determining the impact of sweep on stand value

TLS can be used to determine sweep ratio in standing timber by measuring diameter and center-line displacement to the nearest millimeter, indicating the possibility of using this technology for assessing sweep in stand-level inventory in the future. To evaluate the impact of sweep on value we measured diameters, heights and sweep for the three plots used in this preliminary analysis using TLS in combination with the Treemetrics software. Log specifications and prices were assembled for chiplogs and sawlogs with different sweep classes. VALMAX Optimizer was used to convert the TLS data to volume and value estimates.

We found that, all other things being equal, not taking sweep into consideration would result in an overestimate of stand value by about $800 per hectare (~ 3% of stand value). A small amount of chiplog volume would be incorrectly assessed as sawlog material, but most of the overestimate would be due to an incorrect distribution of sawlog material into less sinuous classes.

As noted above, there have been few, if any, studies that have compared the accuracy of TLS scans with mill scans. Further comparisons between mill scan measurements and TLS scan measurements will reveal the level of accuracy of TLS sweep assessment. This will ultimately determine whether or not TLS technology could feasibly replace current methods of sweep determination in standing timber.

Increasing value with the addition of a veneer line

The mill being supplied from the poplar stands does not currently have a veneer line. The questions arose, "could more value be engineered into the supply chain by the possible addition of a veneer line to the mill?" Log specifications and prices were assembled for chiplogs, veneer logs, and sawlogs. Compared with sawlogs, veneer logs were shorter (1.3 to 2.5 m vs 2.6 to 3.8 m), straighter (maximum sweep allowed was SED/12 vs SED/8 to SED/1), and larger (minimum SED of 200 mm vs 150 mm). VALMAX Optimizer was again used to convert the TLS data to volume and value estimates.

Table 1: Comparison of value recovery before and after the simulated addition of a veneer line
(Plots 2, 3 and 6 in Stand 1)

Plot	Total Volume (m³/ha)	Total Value* ($/ha)	Value Difference ($/ha)	Sawlog (%)	Chip (%)	Veneer (%) (> 200 mm SED)
2	489	$20,910	$1,780	81	19	-
		$22,690		42	19	38
3	642	$30,730	$2,510	85	15	-
		$33,240		43	15	41
6	527	$19,740	$2,860	81	19	-
		$22,600		29	19	51
Average	549	$23,790	$2,390	82	18	-
		$26,180		38	18	43

* Note that total values are based on calculated return-to-log values for logs delivered to the mill-yard. Costs associated with harvesting and transporting logs have not been subtracted from these. Values may, or may not, reflect those obtained by GreenWood Resources.

Table 1 shows the potential value gained by GreenWood Resources though optimally allocating a portion of the sawlogs to veneer production. Preliminary results indicate that by adding a veneer line to the mill the value of the wood in plots 2, 3 and 6 increased by an average of $2400 per hectare. All of the veneer grade wood was projected to come from sawlogs, indicating that changing the allocation of a portion of the sawlogs to veneer production would increase the value of the wood in the stand studied. With further research there is potential for TLS to be used as a tool for predicting optimal product allocation, not only in poplar, but in many other species of standing timber.

Increasing value by changing trucking and/or mill infeed

As noted above, GreenWood Resources bucks all logs at the stump or landing to approximately 17 meters; primarily because 17 m is the maximum length that can be scanned in the mill but also to minimize handling and trucking costs. We determined the amount of sawlog volume that was lost due to bucking to 17 meters for these reasons. TLS and VALMAX were used to generate the percent of sawlogs lost from plots 2, 3 and 6 from this practice (Table 2). These preliminary results show that the percent of sawlog grade wood lost from bucking to 17 meters was significant for this stand. Depending on the value of the sawlogs lost, this could translate to

significant value losses on an annual basis. Possible solutions could be to redesign the trucking and the front of the mill so that longer logs could be trucked and scanned.

Table 2: Percent sawlogs "lost" due to bucking to a 17 m rule (Plots 2, 3 and 6 in Stand 1)

Plot	Total number of sawlogs	Sawlogs lost	% Lost
2	90	8	8.9%
3	114	12	10.5%
6	116	10	8.6%
Average	107	10	9.3%

CONCLUSIONS

Although TLS is being used operationally in some parts of the world for assessing stand value and log product yields, it is in its infancy for many other parts of the world. Few studies have been carried out in hybrid poplar stands. No studies, that we are aware of, have compared mill scan measurements and TLS measurements.

Preliminary results from our study indicate that both the mill scans and TLS scans underestimated stem diameters; the underestimates being greater for the TLS scans. Elliptical stem diameters towards the base of the stem and nodal swelling in the first whorl above the pruned zone may have contributed to inaccuracies in TLS measurements. We believe that changes to software used to process the TLS data, which are currently underway, will address some of these issues. Capturing TLS data during the dormant season, when leaves have fallen, should also result in improved accuracy above the pruned zone.

The high level of detail on stem shape and sweep provided by TLS data, when combined with optimal bucking software, did allow us to evaluate the impacts of stem form on standing tree value. We were also able to assess the potential gains in value that could be obtained by altering practices in the forest (e.g. bucking to different log lengths for trucking) and in mill design (e.g. adding a veneer line or changing the mill scan infeed system).

We believe that TLS shows great promise as a tool for assessing stand value, determining the ability of a stand to meet market requirements, and designing value chain improvements. Analyses of the remaining 57 plots in our study, along with future research and development on TLS technology, will determine the rate at which this promise becomes reality.

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