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Hardwood Initiative – Part 5: Development of new processes and technologies in the hardwood industry (Project 16)

Testing the impacts of tree and stand attributes on the variability of acoustic velocity in standing trees (ST300) and logs (HM200)

by

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Abstract

Hardwood Initiative Project is based on two paradigms. First, the end-use potential and value of a wood product basket can be determined by the properties of its wood and should be quantified as much as possible before trees are harvested. Second, as the correlations between site conditions and wood fibre attributes can be changed by silvicultural treatments, it would be possible to optimize the wood production in terms of quantity and quality through a better understanding of silvicultural impacts on changes in wood fibre properties. This document presents the preliminary results of a research component of the project related to acoustic velocity. It focuses on testing the impacts of tree and stand attributes on the variability of non-destructive velocity (ST300 non-destructive measurement in standing tree) and of destructive velocity (HM200 destructive measurement in log). The acoustic measurements were conducted in 30 plots of sugar maple mixed with yellow birch in New Brunswick. Among the trees measured, 64 trees have been subjected to both non-destructive and destructive velocity measurement. Regression analysis by mixed model showed no significant impact of stand attributes (stand basal area and stand height) on the variation of both velocities. In addition, the defects represented by stem deformation, hole, split, wound, and stump swelling, had no significant impact on both velocities. By cons, the test showed a significant correlation between both velocities and dbh and light crown area of the tree. Non-destructive velocity was better explained by dbh and light crown than the destructive velocity. These results open the potential to produce an equation to predict the non-destructive acoustic velocity of the tree using simple tree attributes (e.g., dbh and light crown) as predictors, and to prescribe the thinning intensity for a desired level of velocity and then a desired level of wood density or stiffness.

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1 Objectives

The objective of the project is to evaluate the impact of tree and stand attributes on two types of acoustic velocity measurements: one measured on standing trees with the ST300 tool (i.e., non-destructive velocity), and the other measured on sawlogs with the HM200 tool (i.e., destructive velocity). The aim is also to evaluate which velocity measurement provides the best accuracy.

2 Introduction

Critical to any forest management plan is the quality and accuracy of the inventory information used. Traditional forest management plans in Canada are based on tree species, tree height, volume, and average piece size such as tree diameter at breast height (1.30 m). The Canadian forest industry is facing economic challenges because of changes in global markets for forest products. Tree grade quality and wood fibre attributes now must be considered in forest inventory procedures. Hence, non-destructive methods must be developed to access the potential inner product quality per tree grade and wood fibre attributes in standing trees.

Theoretically, acoustic velocity (velocity) is related to wood density (green density) and dynamic modulus of elasticity MOE (dynamic stiffness) as follows:

$$v = \sqrt{\frac{MoE}{\rho}} \qquad [1]$$

where v is the acoustic velocity (km/s), MoE is the modulus of elasticity or wood stiffness (N/m^2), and ρ is the wood density (kg/m^3). Thus, the more accurate is the measurement of v by non-destructive device ST300 (http://www.fibre-gen.com/st300.html) or by the destructive device HM200 (http://www.fibre.gen.com/hm200.html), the more promising the derivation of ρ or MoE from Eq. 1 will be. Indeed, Auty and Achim (2008) demonstrated that v and ρ can be used to predict MoE and particularly that v can be used for sorting logs in the sawmill yard. In addition, Jones and Emms (2010) showed that there are strong associations between the log acoustic velocity and branch size variables, the number of branches and whorls. Obtaining the earliest possible assessment of wood quality is essential to the efficiency and the sustainability of the Canadian wood value-chain, i.e., for assessing and tracing wood properties from the standing tree to the end product. Then, it becomes relevant to assess the reliability of v to obtain an early assessment of wood quality on logs (destructive velocity) and especially on standing trees (non-destructive velocity). In addition, as destructive velocity might be more expensive than the non-destructive velocity because it requires harvest, it is justified to quantify the gain in accuracy of the destructive velocity on logs, compared with the non-destructive velocity on trees.

3 Materials and Methods

3.1 Tree and stand measurements

Non-destructive acoustic velocity was measured on 40 sugar maple (*Acer saccharum Marsh.*) trees and 24 yellow birch (*Betula alleghaniensis* Britton) trees sampled from sixteen 400 m^2 circular plots. Plots were distributed across two forest eco regions in New Brunswick (Figure 1). Two stand attributes were considered: basal area (m^2/ha) and mean dominant height (m) (Table 1). The measured tree attributes were stem diameter at 1.30 m (dbh), total height, and crown variables, i.e., crown width, base of light crown (ZM), and lowest base of the crown (ZB) (Figure 2). These crown variables allowed computing two types of crown area: total crown area and light crown area.

Two types of tree defects were measured. First, the stem deformation (curvature and elbow) is quantified by the ratio depth/length. Second tree defect was recorded as hole, split, wound, or stump swelling and these variables were estimated by their area (width x length).

Each of the 64 trees was bucked, and destructive velocity was measured on each sawlog produced. The destructive velocity in the tree is the mean velocity in logs weighted by the log volumes; each log was assumed to be a truncated cone.

Figure 1 Plots location in New Brunswick

Table 1 Data summary

Variable	Sugar maple n=40				Yellow birch n=24			
	Min	Max	Mean	Std	Min	Max	Mean	Std
Stand basal area m^2/ha	14.00	33.00	25.18	5.86	14.00	33.00	23.96	4.94
Stand height m	17.65	24.50	21.06	2.11	17.40	21.42	18.85	1.29
Dbh cm	24.00	48.00	33.40	6.93	24.00	50.00	33.42	7.06
Crown width dm	15.333	39.67	28.47	6.01	17.67	45.33	31.91	6.03
Total crown area m^2	163.28	673.14	384.97	106.18	171.54	714.00	399.89	123.97
Light crown area m^2	130.55	646.57	342.67	116.09	155.11	638.86	327.85	113.34
Non-destructive velocity km/s	2.94	4.08	3.58	0.27	3.37	4.30	3.88	0.23
Destructive velocity km/s	3.25	4.69	4.07	0.26	3.82	4.71	4.30	0.23

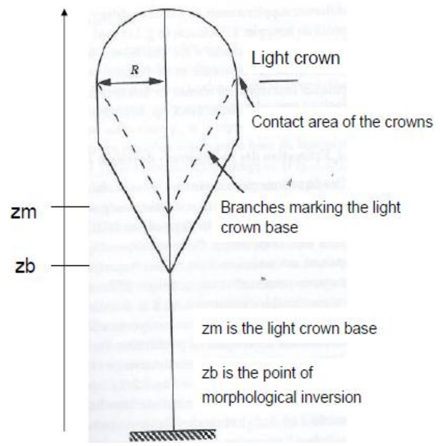

Figure 2 Crown parameters

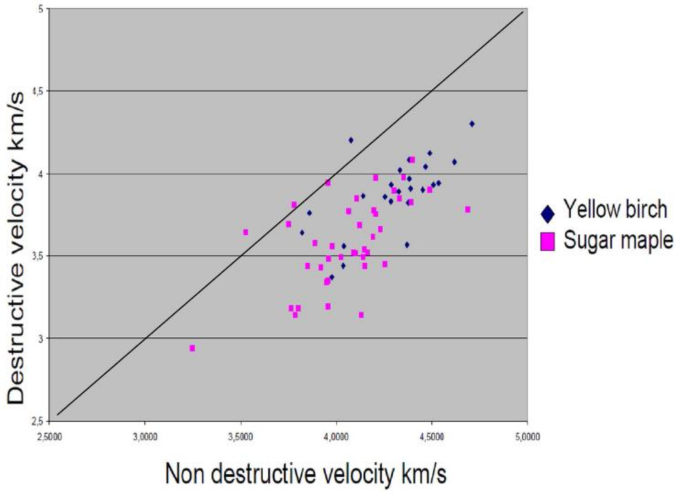

Figure 3 Non-destructive velocity vs. destructive velocity, each point represents one tree

3.2 Method of analysis

The following linear regression was used to address both objectives:

$$v_{ij}= \mu + S_j + T_{ij} +e_{ij} \qquad [2]$$

with v_{ij} acoustic velocity of tree i in plot j, μ the overall population mean, S_j the fixed effects of stand attributes, T_{ij} the fixed effects of tree i attributes in plot j, and e_{ij} random error of tree i in plot j. The mixed model procedure was used for separating the fixed effects of tree and stand attributes from the random effect. After confirming that tree species effect was significant, sugar maple and yellow birch were considered separately.

4 Results and Discussion

Tree species effect was significant on non-destructive and destructive velocity (Table 2). Stand attributes represented by stand basal area and stand height were not significant on both velocities and for both species (Table 3). The insignificant impact of stand attributes should be caused by the relatively narrow range of the observed stand basal and stand height. None of the considered tree defects had significant effect on both velocities and for both species (tests not shown). Apparently, this lack of correlation seems to contradict Sandoz and Lorin (1996) who advocated the use of acoustic velocity for detecting gross defects on standing trees (cavity, advanced decay or soft rot). However, in reality, this lack of correlation in our data simply means that the observed defects are not quite as advanced as the defects considered by Sandoz and Lorin (1996). It is clear that tree dbh, tree crown width, and light crown area explain significantly both velocities and for both species. The fact that light crown and dbh had significant impacts on the velocity opens the prospect that the acoustic velocity measurement becomes a tool that can help to optimize the wood production in terms of quantity and quality through a better understanding of silvicultural impacts on changes in wood fibre properties. In fact, by releasing the selected tree, thinning acts directly on its crown shape and alter the proportion of light crown compared with the shade crown (Ung *et al.* 2009). It would be therefore possible to produce an operational prescription of the thinning intensity based on a desired level of velocity. This prescription would be based on the following equation:

$$v = aA^{b}DBH^{c} \qquad [3]$$

v is the non destructive velocity, A is the area of the light crown (light crown length x crown width), DBH is dbh, a, b and c are the parameters to be estimated by regression with :

$$c = c_1 + c_2\,CI \qquad [4]$$

CI is the competition index from neighbour trees on the selected tree, and could be computed as follow:

$$CI = \sum_{i=1}^{n} \frac{A_i}{D_i} \qquad [5]$$

A_i is the light crown area of the neighbour tree i, and D_i the distance between the selected tree and its neighbour i. CI is an indicator of stand structure at the local scale and would be useful not only to predict the velocity, but also to prescribe the thinning intensity in terms of distance between the selected tree and its neighbours. Equations 3, 4 and 5 offer the possibility to use data extracted from terrestrial LiDAR to predict velocity and related wood stiffness, in turn, closely correlated to wood density. These equations also open the prospect of using aerial LiDAR data for the same prediction. However, a loss of accuracy must be accepted as dbh must be replaced by tree height in Equation 3.

Finally, the destructive velocity offers no appreciable gain in precision compared to non-destructive velocity. Therefore, at the tree scale and not at the log scale, the non-destructive velocity offers one of the best options for deploying the velocity assessment on standing trees (Table 4). However, this gain is less clear for yellow birch because the number of sampled yellow birch trees is lower than the number of sugar maple and the range of the observed velocity for yellow birch is smaller than the sugar maple (Figure 3). Like Mora et al (2009), non-destructive velocity is higher than destructive velocity. Indeed, the scatter point of destructive velocity versus non-destructive velocity is beneath the line 1:1. As Mora et al (2009) have reminded, the non-destructive velocity measurement is sufficient for providing rapid information for ranking purpose such as for prescribing the thinning. However, the precise derivation of the stiffness of the standing tree from the non-destructive velocity must take account of wood moisture and wood density.

Table 2 Tree species effect on non-destructive and destructive velocity

Numerator degree of freedom=1 Denominator degree of freedom=62	Effect	F value	Pr >F
Non-destructive velocity	Tree species	12.72	0.0007
Destructive velocity* (avg. per tree)	Tree species	19.54	<0.0001

(*on sawlogs only)

Table 3 Effects of dbh, tree height, tree crown, stand basal area and stand height on non-destructive and destructive velocity

Sugar maple: numerator degree of freedom=1; denominator degree of freedom=29				
	Non-destructive velocity		Destructive velocity	
Effect	**F value**	**Pr >F**	**F value**	**Pr >F**
Dbh	37.96	<.0001	3.09	0.0893
Tree height	2.37	0.1343	4.17	0.0503
Crown length 1	8.69	0.0063	0.02	0.8940
Crown length 2	7.24	0.0117	0.00	0.9593
Crown width	0.92	0.3447	0.11	0.7429
Crown length 1x Crown width	11.49	0.0020	0.01	0.9090
Crown length 2x Crown width	9.95	0.0037	0.07	0.7896
Stand basal area	4.35	0.0459	0.71	0.4064
Stand height	0.28	0.6025	1.66	0.2083

Yellow birch: numerator degree of freedom=1; denominator degree of freedom=13				
	Non-destructive velocity		Destructive velocity	
Effect	**F value**	**Pr >F**	**F value**	**Pr >F**
Dbh	3.61	0.0798	5.24	0.0395
Tree height	0.70	0.4193	4.87	0.0459
Crown length 1	0.16	0.6968	0.50	0.4903
Crown length 2	7.24	0.0117	1.34	0.2683
Crown width	0.08	0.7781	0.48	0.4999
Crown length 1x Crown width	0.00	0.9449	0.28	0.6063
Crown length 2x Crown width	0.25	0.6242	1.35	0.2669
Stand basal area	0.64	0.4377	1.31	0.2728
Stand height	0.72	0.4127	0.99	0.3371

Table 4 Variance residual of the equation $v_{ij}= \mu + T_{ij} + e_{ij}$ with T_{ij} represented by dbh, light crown area of tree i in plot j

	Sugar maple	Yellow birch
Non-destructive velocity	0.019	0.052
Destructive velocity	0.037	0.040

5 Conclusions and Recommendations

Dbh and light crown are the most correlated with acoustic velocity. This result is very comforting because it indicates that thinning affects velocity in promoting the dbh increment and tree crown expansion. In addition, this result opens the prospect of producing models for predicting the velocity based on the tree attributes (light crown with dbh or height) that can be obtained by traditional field measurement, terrestrial LiDAR or aerial LiDAR. For this prediction, the gain of accuracy provided by the destructive velocity is zero compared with the non-destructive velocity.

These results support the two following recommendations:

1. To build an acoustic velocity database for sugar maple and yellow birch of Eastern Canada, the database reassembles the following data: plot latitude-longitude, subject tree dbh, subject tree height, subject crown width, subject light crown length, subject non-destructive acoustic velocity, distances between subject tree and neighbour trees, neighbour tree crown width and neighbour tree light crown length.

2. To produce and test for operational application the equation (Eq. 3, 4 and 5) for predicting non-destructive velocity based on dbh, light crown and inter-individual competition index.

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