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Sorting of logs using acoustics

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Abstract The practical implications and benefits of using acoustics for sorting pine logs at the skids is reported. The aim is to segregate logs according to their intrinsic stiffnesses and to determine the proportion of lumber making framing or structural grades. The proposition is that there are significant financial benefits to sawmillers if the poorest logs – those which yield low stiffness timber – can be identified and diverted to other end uses that do not require high stiffness.

Introduction

There is an urgent need to allocate wood more effectively between industries, to ensure that wood is used more efficiently in final end use. For such an approach, the appropriate task is to see that a particular log or piece of lumber is allocated to that industry that can best use its specific and peculiar properties.

Currently logs are graded on the skids according to length, diameter, sweep and taper and to visual features (knot size and distribution, wounds and other defects). Further, account can be taken of the stand age and management history. However, once the logs have been sorted into stacks on the skids, all logs within a stack are deemed identical in so far as there is no basis for further differentiation. Herein lies an opportunity. A study of a stand of pine in Canterbury, New Zealand, has shown that the variation in the intrinsic properties between visually identical logs is considerable (Addis Tsehaye et al. 1995), with the top 10% of the logs yielding lumber whose average stiffness is 80% greater than the average for the poorest 10% of the logs. Wood characteristics are also effected. Those same logs which yielded the stiffest lumber also had the longest tracheids in both corewood and outerwood, the highest cellulose yields and conversely the lowest lignin contents (Addis Tsehaye et al. 1998).

In a subsequent study of log quality for pine in Nelson, New Zealand, 93 logs were tapped at one end, and the time of flight for sound from one end of the log to

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the other was measured. The logs were then sorted into three groups of 27, 39, 27 logs respectively, according to the speed of sound along the logs. Those logs with the fastest velocity of sound yielded lumber which was 90% stiffer than the group in which sound travelled slowest (Addis Tsehaye et al. 1997), and a similar effect for tracheid length, cellulose content and lignin content as was observed for Canterbury was found (unpublished). Acoustic sorting of logs appeared to offer a means of pre-sorting logs according to intrinsic wood quality of their lumber prior to sawmilling.

Thus, by way of an example, pre-sorting logs prior to milling would allow mills cutting structural lumber to buy only those logs which are capable of returning a high percentage of framing and structural grades, whilst a mill with a board finger-jointing line might be willing to purchase the logs whose wood is intrinsically less stiff. The work reported here relates to a much larger study than hitherto carried out and examines the improved grade recovery and economic return from log sorting using acoustics. The study examines logs and lumber coming from a 27-year old, unpruned stand from the Central North Island and compares data with the earlier study in Nelson.

All three unpruned stands, in Canterbury, Nelson and on the Mamaku Plateau of the Central North Island, were on land of low site index and had received little or no silvicultural management. They were chosen to typify such unpruned stands.

Methods

Three hundred logs 4.2 metres long were taken from a 27-year-old pine plantation on the Mamaku Plateau in the Central North Island. The stand, established in 1971, had the following characteristics at age 25 (pers. com. Marco Lausberg):

- Mean DBH = 33.15 cm;
- Mean top height = 30.15 m;
- Mean stocking 694 sph;
- No silvicultural management (i.e. no thinning and no pruning).

The time of flight for sound along the logs was measured with a Metriguard Model 239A Stress Wave Timer. One end of each log was hit with a hammer containing an accelerometer that registers the moment of impact. The sound wave passes along the log and its arrival at the other end is detected by a second accelerometer that was firmly pressed (dry coupling) against the other end of the log by another person. The propagation time of the sound wave signal was determined from the difference in the arrival times of the transmitting and receiving signals. Each log was struck six times and the average of the six times of flight was used for further analysis.

At the sawmill the logs were cant-sawn to the pattern shown in Figure 1, as described in Addis Tsehaye et al. (1995). The position of every board was identified and recorded according to log type (butt, second, third, top). The lumber was then kiln-dried to 12% moisture content, dressed to 90 × 35 mm and machine stress graded to the Australian grading rules (SAA 1978a, b). The modulus of elasticity in bending was determined as each board passed over rollers set at a span of 914 mm in the stress-grading machine, by applying a constant force and recording the resulting deflection at 152 mm intervals along the length. These MOE values were captured on computer using Tadpole software[1].

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[1] © Mr Denis Grant (1998).

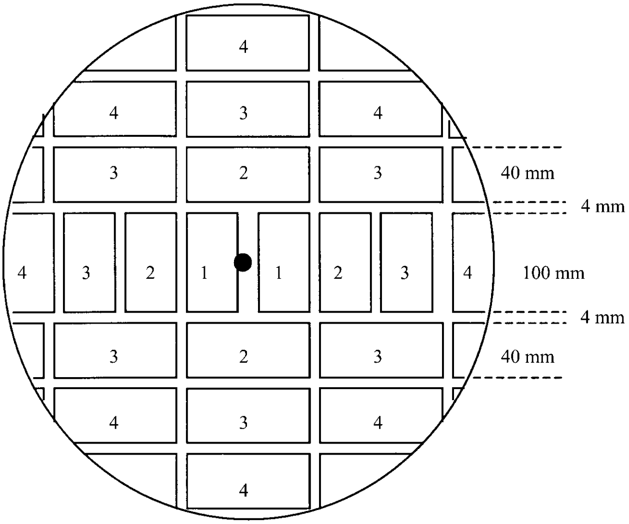

Fig. 1. Sawing pattern, cutting a 100 mm thick central cant and 40 mm wide flitches to give 100 × 40 mm green and 90 × 35 mm dry, dressed boards

Results and discussion

Mamaku data

Table 1 presents a summary of the mean modulus of elasticity values and the grade recovery of structural lumber cut from all 300 logs sorted into nine groups according to (velocity of sound)^2. These nine groups provide a broad range of velocities and stiffnesses. The average stiffness of the wood within each log is taken as equivalent to the average stiffness of all boards cut from that log, taking the average stiffness of the wood along an individual board as the value for that board. Note that the proportion of F4 and lower grades decreases steadily as the (velocity of sound)^2 increases and that F5 & above is usually required for framing timber.

Table 1. Mamaku data: a summary of mean stiffness of all boards and grade recovery of lumber cut from each of the 300 logs sorted by (velocity of sound)^2 and segregated into nine groups

Group	No. of logs	V^2 in logs ($\times 10^6$ m^2/s^2)	No. of boards	Mean MOE of boards (GPa)	%F4 & below	%F5	%F8 & better
1	11	4.60	162	6.3	54.3	38.3	7.4
2	42	5.48	464	6.9	52.8	40.1	7.1
3	62	6.45	624	7.7	35.9	43.8	20.3
4	80	7.40	619	8.0	32.1	44.6	23.3
5	63	8.39	384	8.1	29.9	39.6	30.5
6	28	9.34	183	8.6	22.9	36.1	41.0
7	7	10.29	34	9.5	14.7	29.4	55.9
8	4	11.35	24	9.9	16.7	37.5	45.8
9	3	13.03	12	10.2	0.0	41.7	58.3
All	300	7.40	2506	7.9	36.8	41.5	21.7

The relationship between the velocity of sound and the mean modulus of elasticity was established by regressing the (velocity of sound)^2 against the modulus of elasticity as shown in Figures 2a and b. A summary of the statistical values for the linear regression analysis between the (velocity of sound)^2 of logs and MOE of the boards is presented in Table 2.

Nelson data

The results in Tables 1 and 2 can be compared with an earlier, more limited study on ninety three logs, each 4.2 metres length, that were randomly selected from a 25-year-old unpruned pine plantation in the southern Pigeon Valley, Nelson. A

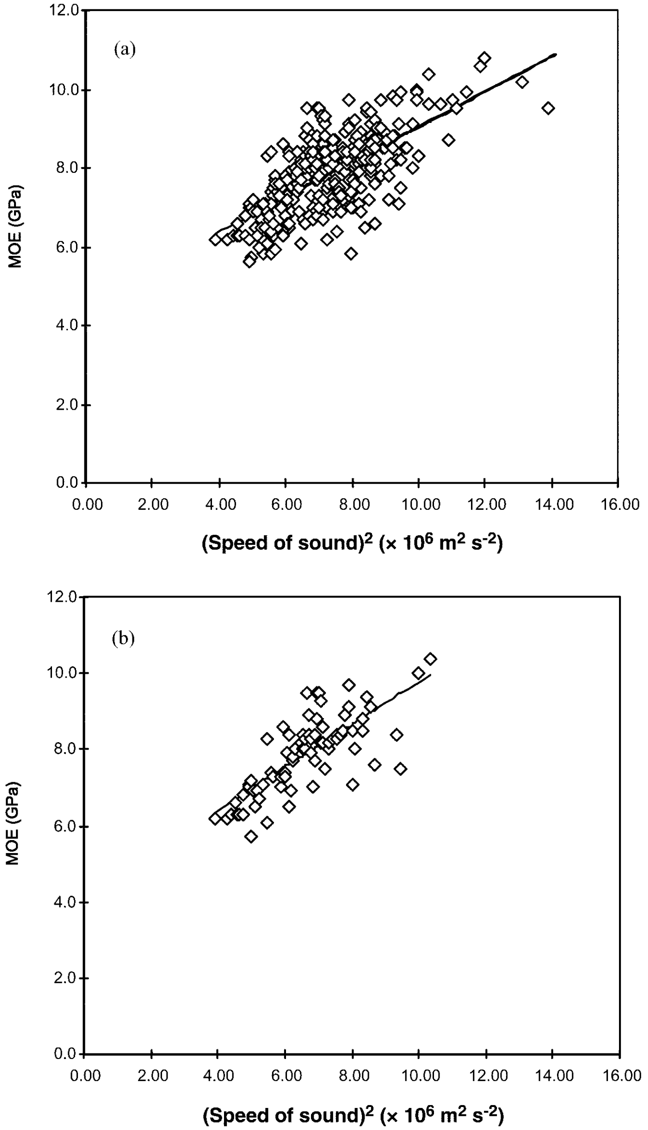

Fig. 2a, b. MOE vs. velocity^2: (**a**) for all logs and (**b**) for butt logs from Mamakus

Table 2. Mamaku data: statistical values from the linear regression analysis between the (velocity of sound)^2 of the logs and average MOE of the boards

Log type	No. of logs	Constant (10^6 m^2/s^2)	x-coefficient (10^6 m^2/s^2)	R^2 (%)
Butt	80	4.147	0.564	57.0
Second	80	4.726	0.440	48.0
Third	78	4.209	0.462	48.0
Top	62	4.193	0.467	45.0
All logs	300	4.611	0.443	46.0

previous report (Addis Tsehaye et al. 1997) on log segregation strategies compared the (velocity of sound)^2 of the logs with only the pith-containing lumber; in order to make the appropriate comparison with the current logs from Mamaku, the Nelson data has been reanalysed, considering all the boards coming from each log. The results are presented in Tables 3 and 4.

Unlike Table 1 in which the mean MOE of the boards increases steadily with the (velocity of sound)^2, there is less consistency in Table 3. Possible reasons for this are discussed in the next section. However, the sorting at the extremes i.e. between the least stiff and high stiffness groups remains effective.

Table 4 summarises the statistical values for the linear regression analysis between the (velocity of sound)^2 of the Nelson logs and average MOE for their boards. Fig. 3a and b show this relationship for all logs and butt logs.

Table 3. Nelson data: summary of mean stiffness of all boards and grade recovery of lumber cut from each of the 93 logs sorted by (velocity of sound)^2 and segregated into nine groups

Group	No. of logs	V^2 in the logs ($\times10^6$ m^2/s^2)	No. of boards	Mean MOE (GPa) of boards	%F4 & below	%F5	%F8 & better
1	8	6.33	33	5.8	30.3	45.5	24.2
2	12	7.20	75	7.1	17.4	29.3	53.3
3	12	8.30	90	7.7	14.4	42.2	43.4
4	12	9.25	79	7.3	29.1	38.0	32.9
5	12	10.28	86	8.8	10.5	25.6	63.9
6	6	11.57	41	8.4	12.2	29.3	58.5
7	5	12.35	29	7.2	10.3	20.7	69.0
8	13	13.97	106	9.6	17.9	19.8	62.3
9	13	15.59	115	10.7	9.6	13.0	77.4
All	93	10.61	654	8.3	16.2	27.7	56.1

Table 4. Nelson data: statistical values from the linear regression analysis between the (velocity of sound)^2 of logs and average MOE of their boards

Log type	N	Constant (10^6 m^2/s^2)	x-coefficient (10^6 m^2/s^2)	R^2 (%)
Butt	25	3.062	0.461	57.0
Second	25	3.010	0.547	62.0
Third	24	5.019	0.331	31.0
Top	19	4.082	0.337	32.0
All logs	93	3.690	0.430	47.0

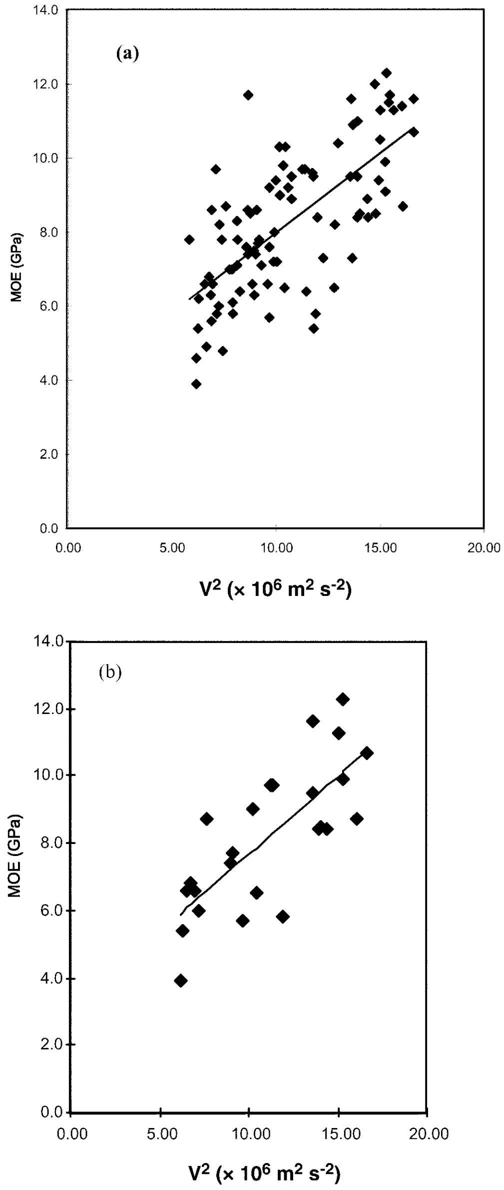

Fig. 3a, b. MOE vs. velocity^2: (**a**) for all logs and (**b**) for butt logs from Nelson

Comparison of results

The apparent velocities of sound along the logs from the Mamaku Plateau are somewhat slower (10–20%) than for the logs from Nelson when comparing logs yielding boards having similar mean MOEs (Tables 1 and 3). The most probable explanation lies with the experimental techniques and procedures.

There are random and systematic errors, due to the impedance offered by the roughened surfaces at either ends of the log through which the acoustic wave front must enter and leave. In a separate study large delays were observed where the cut surfaces were very rough and broken, as with tree-shears, and even with a clean chainsaw cut the impedance can be quite variable depending on how effectively the receiver is placed on the rough surface. Also there is mud. It is likely that this is the principal explanation for the differences between the two studies. Intimate acoustic coupling minimises such errors but it is difficult to guarantee this under field conditions. Alternatively, the non-contact resonance approach advocated by Nakada et al. (1998) should be considered.

The time of flight is affected by the crispness of the impact and whether the log is hit near the pith or cambium. With regard to the latter, the logs were always struck on the third ring from the pith and the detector was similarly placed at the other end of the log. However, the steepness of the wave front, the ability of the wave front to fill the entire cross-section of the log, and the threshold value at which the detector is triggered are operator dependent and are another source of variation.

Again, with regard to acoustic sorting, the Nelson logs were sorted while in stack, whereas for the Mamaku trial the logs were lying individually along a roadside. Green and Ross (1997) report similar velocities whether the logs were in stack or isolated, whereas in a limited study we recorded a 4% increase in velocity with stacked logs (unpublished).

The dried, dressed lumber was machine stress graded on two machines (in Nelson and Bay of Plenty) which are unlikely to be adjusted identically.

Finally, a small number of boards (ca. 5%) with large knots break during the normal coarse of milling and subsequent handling. Most were recovered, but if lost, their omission would result in that log appearing stiffer than it really was.

The observed scatter in Figs. 2 and 3 and the correspondingly modest regression coefficients in Tables 2 and 4 are consequences of these random and systematic errors, and of using first generation acoustics technology for sorting logs. However, the essential point is that some segregation is achievable (even if segregated populations overlap significantly) and there are economic benefits. This study clearly understates the potential benefits of sorting logs with acoustics.

Financial returns

The current wholesale prices for machine stress graded radiata pine lumber for F4 & below, F5 and F8 & better are NZ $277/m^3, NZ $430/m^3 and NZ $450/m^3, respectively (Pers. com. Mr. P. Simperingham, Carter Holt Harvey Timber Company). An indicator of the potential financial benefit if acoustic log sorting

Table 5. Comparison of financial returns for the logs from the Mamaku Plateau and Nelson ($/m^3)

Source:	Mamaku					Nelson			
Group	%F4 × $277/m^3	%F5 × $430/m^3	%F8 × $450/m^3	Total $/m^3	Group	%F4 × $277/m^3	%F5 × $430/m^3	%F8 × $450/m^3	Total $/m^3
1	150	165	33	348	1	84	196	109	389
2	146	172	32	350	2	48	126	240	414
3	99	188	91	378	3	40	181	195	416
4	89	192	105	386	4	81	163	148	392
5	83	170	137	390	5	29	110	288	427
6	63	155	185	403	6	34	126	263	423
7	41	126	252	419	7	29	89	311	429
8	46	161	206	413	8	50	85	280	415
9	0	179	262	441	9	27	56	348	431
All	102	178	98	378	All	45	119	252	416

was feasible is outlined in Table 5. The table compares the financial return for each group sorted by (velocity of sound)^2 on the basis of their grade recoveries.

It can be seen that the revenue (\$/m^3) increases steadily from group 1 to group 9. The trend of increasing revenue from logs displaying faster transit times is especially significant for the Mamaku logs. The dollar value for the least stiff logs is much less than for the rest of the population. This shows that if one were able to identify the least stiff logs at the skid site, one could avoid cutting poor quality framing lumber from these intrinsically low-stiffness logs and reduce the cost of misallocation of resources.

Conclusions

The following conclusions are drawn from this study:

1. Acoustic sorting of logs provides the opportunity to send only the best quality logs (high stiffness) to the sawmill;
2. The resulting financial returns from acoustic sorting of logs for structural lumber appear attractive; and
3. More work is needed to characterise the minimum acoustic velocity for logs yielding structural lumber.

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