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LINKING LOG CALIPER INFORMATION TO A SAWING SIMULATOR

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SUMMARY

This study examines the potential of using log information recorded by Timber Tech calipers to derive predicted mill outturn with a computer-based sawing simulator (AUTOSAW).

AUTOSAW is normally used with detailed three-dimensional descriptions of the internal and external features of a log. The approach taken in this study was to use a set of unpruned logs from the AUTOSAW database to test how the simulator would perform with much lower levels of log measurement detail.

A base set of 15 radiata pine second-logs was sawn in AUTOSAW, and the sawn produce graded to NZ visual structural grades. Statistical analysis of the simulation results showed that:

- Sawn timber volume can be predicted to within ±10% using log sed, led and length. This error can be halved by using a series of stem diameters. A further small improvement in prediction is achieved when log sweep is provided.
- Sawn timber grade was poorly predicted using only log sed, led, and length. Prediction error can be substantially reduced if the single largest branch per log is provided. A further small improvement in prediction is achieved by providing the largest branch per whorl. No improvement was achieved using the number of whorls, sweep or more detailed log shape measurements.

Overall this study showed that AUTOSAW's prediction of sawn timber grade outturn for individual logs using the current level of information from Timber Tech calipers was very imprecise and of little practical value. Further research on innovative ways of providing more information for processing simulators is indicated.

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INTRODUCTION

At maturity trees are felled, limbs are trimmed, and the green crown topped. From then onwards there are numerous decisions to be made at each stage of the value chain – from stem bucking (log cross-cutting), log allocation, through log processing – before the production of marketable products. A review of relevant research pertaining to this section of the forestry value chain is given in Appendix A.

As the consequences of any initial decisions may impact all processes in the value chain, the initial decisions, together with the measurements that are used to generate a solution, are of primary importance. Generally, initial solutions are based on stem/log diameter measurements and other branch/defect measurements. However there are many other variables that contribute to the production and performance of the final product:

- log shape (eg sweep, taper, eccentricity of the cross-sections)
- internal defects (eg resin pockets, centrality and sinuosity of the pith, branching patterns - spatial arrangement of whorls/branches, number of whorls/ branches, branch sizes - and, for pruned logs, defect core size)
- wood properties (wood density, spiral grain, microfibril angle, compression wood, earlywood and late wood, core wood to outerwood ratio, fibre properties, ring width, and age).

Ideally, all measurements would be recorded, all processing scenarios examined, and all combinations of all product types compared. Some of the key log types, processes, and products that are contained within the chain are listed in Table 1 below. The combinations and permutations of all these elements produce a huge combinatorial problem, requiring intensive measurements, and is not practical in the real world.

Table 1: Factors influencing the decision-making process

Log Categories	**Processes**	**Primary/Secondary Products**
Pruned	Peeling	Veneer
Unpruned	Sawing	Boards
	(live, cant, around, quarter)	Squares
Height classes	Pulping	Pulp / paper
	Chipping	Chips / reconstituted wood products

In the past, actual sawing studies have been used to find the links between log variables and sawn outturn (see literature review; Appendix A). These studies have resulted in the development of a series of regression equations that are now used in SAWMOD. Computer sawing simulation systems have also been developed to examine the effect of changes in parameters (log data, or sawing, or sawmill variables) on sawn outturn. Whilst regressions serve to fill gaps in knowledge, they do not offer the same flexibility as offered by simulation tools.

A condition of log processing simulation models is that they require detailed three dimensional data models of a log's shape and internal defects to provide accurate predictions. The objective of this project was to examine the potential of using the limited log information provided by the TimberTech calipers to predict mill outturn and allow for better matching lines of logs to lumber orders.

METHODS

In this exercise the information gap between Logger caliper measurements and the requirements of a simulation model was filled with "real" data; with log models constructed from intensive measurements of real log profiles and branching patterns.

Due to the combinatorial nature of the problem, a full analysis of all possible log variables, processing options, and product types was beyond the scope of this current project. Therefore this investigation focused on a well-defined subset, i.e:

Log type: Unpruned

Log variables: Measures of log shape (taper, sweep, cross-sectional diameters) and measures of branching patterns (maximum branch size per log, maximum branch size per whorl, and the number of whorls per log).

Processing: Sawing simulation, in AUTOSAW, to a cant sawing pattern

Products: Boards - applying NZ standard for visual structural grades (Engineering, Framing 1, Framing 2, Box)

Original Logs

A set of 15 unpruned radiata pine second logs, from Kaingaroa Forest, formed the basis for all work presented here. Data from these logs (including branching patterns) enabled the reconstruction of virtual 3D logs (labelled Oi, i = 1..15, Appendix B). The virtual logs were all standardized to a length of 5m and the branch condition adjusted so that 2/3 of each branch was assumed to be live and the remaining 1/3 dead. General log characteristics are shown in Tables 2 and 3.

Table 2: General characteristics of base logs

Log	SED (mm)	LED (mm)	Sweep (mm/m)	Max branch diam (mm)	Number of whorls
1	346	372	5	70	15
2	356	391	3	54	10
3	331	393	3	68	11
4	429	465	4	62	12
5	366	404	5	62	12
6	440	456	4	74	8
7	369	401	3	98	14
8	240	273	6	54	10
9	415	492	4	76	10
10	311	329	3	48	9
11	306	362	6	66	12
12	207	238	10	42	10
13	439	485	7	130	8
14	339	375	5	94	10
15	207	214	6	32	7

Table 3: Volume, sawn timber values and timber grade percentages by volume of base logs

Log	Volume (m^3)	Value ($\$/m^3$)	%Eng	%Eng+1F	%Eng+1F +2F
1	0.361	168	0.0	0.0	10.2
2	0.390	219	10.1	22.4	45.3
3	0.369	163	0.0	1.8	1.8
4	0.538	231	8.7	27.5	56.1
5	0.434	187	0.0	1.7	32.2
6	0.562	173	0.0	3.6	12.9
7	0.406	171	0.0	0.0	13.9
8	0.157	207	0.0	2.9	55.7
9	0.513	189	3.6	3.6	30.0
10	0.286	248	10.5	31.7	72.0
11	0.329	176	0.0	3.4	16.6
12	0.085	234	0.0	30.9	61.9
13	0.601	176	0.0	0.0	20.0
14	0.298	160	0.0	0.0	0.0
15	0.096	229	0.0	27.6	58.4
Mean	0.362	195	2.2	10.5	32.5
s.d.	0.160	30	4.0	13.1	23.9

Synthesised Logs

The above set of 15 logs formed the basis from which a further 4500 virtual logs were generated. These virtual logs had variations in log shape and branching as follows:

Log shape and sweep

For each of the 15 logs, a simple and a complex log shape was generated. The simple shape was formed using a truncated cone based on the length, SED and LED of the log. The complex shape consisted of a series of truncated cones based on sectional diameters.

Each shape was applied without any sweep, and with sweep (by bending each log at the mid-point to produce the same measure for sweep as for the original log).

This generated four basic log profiles (two shapes types, with and without sweep) for each original log. These shapes can therefore be described in terms of the two experimental factors:

- Log shape - simple and complex
- Sweep - straight and swept

Branching

Five different methods were used to generate branches for the virtual logs using the original 15 logs as their basis. Each method used the branches from all 15 logs, these were placed inside each of the 15 subject logs, generating 225 logs per method. The methods were as follows:

1. Unadjusted - the 15 branch patterns were placed inside each log without adjustment for size.
2. Adjusted to maximum branch per log - branches were scaled to have the same maximum branch diameter as the subject log.

3. Adjusted to maximum branch per whorl - branches in each whorl were scaled to the maximum branch in the corresponding whorl of the subject log.
4. Adjusted to maximum branch and number of whorls - branches were scaled as in (2.), and the number of whorls was also adjusted to correspond to the subject log.
5. Adjusted to maximum branch per whorl and number of whorls - branches were scaled as in (3.), and the number of whorls was also adjusted to correspond to the subject log.

These five branch patterns can be best considered as the product of two experimental factors:

- Branch diameter - unadjusted, adjusted to max branch per log, adjusted to max branch per whorl
- Number of whorls - unadjusted, adjusted

In all, with two shapes, two sweep types, and five branch methods, 20 treatment combinations were generated. Further details of the virtual logs are given in Appendix B.

Sawing Simulation

All sawing simulations were performed using the AUTOSAW system, this is the parent simulation system behind TreeMAPs. The virtual logs were cant sawn, with a cant size of 200 mm being cut from logs with an SED greater than 300 mm, and a 100 mm cant for smaller logs. Boards were primarily 40 mm thick, some 25 mm boards also cut. Board widths of 100, 150 and 200 mm. Half-taper sawing, logs positioned with plane of sweep up (ie horns down). All saw kerfs were 3 mm. Simulated timber dimensions and grades processed in Sawnout to produce a summary, for each log, of sawn timber volume by grade.

Price list

Boards were valued using the latest domestic timber price list for Radiata Pine included in SAWMOD 6.30.

Timber Grade	AUTOSAW Grade code	Timber Price ($\$/m^3$)
Box	p	160
No. 2 Framing	z	240
No. 1 Framing	y	320
Engineering	e	370 (equated to No. 2 clears)

Statistical Methods

For each of the original 15 logs, and the 4500 virtual logs, the following variables were obtained:

- Volume of sawn timber (m^3)
- Value of sawn timber ($\$/m^3$)
- Actual volume of sawn timber by grade
- Percentage volume by grade

Percentage volume by grade was expressed cumulatively starting with the most valuable grade, ie, %Eng, %Eng+1F and %Eng+1F+2F.

Each of the 4500 virtual logs was based on one of the 15 original logs. In other words, each subject log was matched by 300 virtual logs, containing greater or lesser amounts of shape and branch information from the original log. For each virtual log, the following values were calculated for value of sawn timber and percentage volume by grade:

1. Mean error (bias) = Actual - Simulated

where "Actual" is the value obtained from the actual 3D log model and "Simulated" is the value obtained from the given virtual log. Mean error indicates whether the simulation is introducing gross errors, eg if the simulation is less than actual. However even where bias = 0 there can still be considerable variation. MSE was used to quantify this.

2. Mean Squared Error (MSE) = $(\text{Actual - Simulated})^2$

Because the distribution of MSE was generally highly skewed, its square root (SMSE) was analysed. It should be noted that SMSE gives a good general idea of how well the simulated logs are representing the subject log. If the bias is practically zero, this approximates the standard deviation of the difference between actual and simulated values.

An analysis of variance (ANOVA) was then used to test the significance of the following experimental factors on the bias and MSE:

- Log shape - simple and complex
- Sweep - straight and swept
- Branch diameter - unadjusted, adjusted to max branch per log, adjusted to max branch per whorl
- Number of whorls - unadjusted, adjusted

This analysis also included subject log as a blocking factor to reduce experimental variation.

RESULTS

Value of Sawn Timber

Table 4 shows the bias and SMSE calculated for sawn timber value using the timber prices given above. Bias in timber value was small for all simulated logs. This indicates that the simulation did not lead to any *consistent* error in sawn timber value.

However, the SMSE values are high relative to the mean value of $195/m³. This indicates that the simulated logs differed markedly in value to the actual logs. There was about a 50% reduction in SMSE when information on branch sizes was added. Most of this reduction was achieved by using the single largest branch per log, although there was some further reduction obtained by using largest branch per whorl. These effects were statistically highly significant. Adjusting the number of whorls to agree with the subject log had no measurable influence on timber value SMSE, and neither did the inclusion of a measure for sweep.

Table 4: Effects of experimental factors on bias and SMSE of sawn timber values

Experimental factor	**Level**	**Bias ($/m³)**		**SMSE ($/m³)**	
Log Shape	simple	4.8	a	31.1	a
	complex	3.1	a	31.4	a
Sweep	straight	3.3	a	31.7	a
	swept	4.5	a	30.7	a
No. whorls	unadjusted	4.5	a	31.0	a
	adjusted	3.4	a	31.5	a
Branch diameter	unadjusted	1.2	a	47.5	b
	adjusted to max branch	3.5	a	24.5	a
	adjusted to max branch per whorl	7.1	b	21.8	c

Values for each factor followed by the same letter do not differ significantly (p=0.05).

More detail of these results is given in Figure 1 where the SMSE is shown for each of the 20 log sets, each made up of a different treatment combination. The log set obtaining the smallest error term (ie closest to value of O logs) (see appendix B) was the U log set followed closely by the R, S, and T log sets and the M, N, P, Q sets. Each contained branch size and whorl number. The large reduction in SMSE when some information on branch sizes was added is clear (for example when comparing E,F,M,N with C; G,H,P,Q with A; I,J,R,S with D; K,L,T,U with B). With no branch size information (ie when sweep information only was added) the SMSE reduced by about 6% (eg comparing C with A; and D with B).

Overall, even when maximum branch information for each whorl is added the error is very large. If SMSE is taken as a standard deviation this implies that the range in the difference between predicted and actual timber value is ±(21.8 x2) = $43.6.

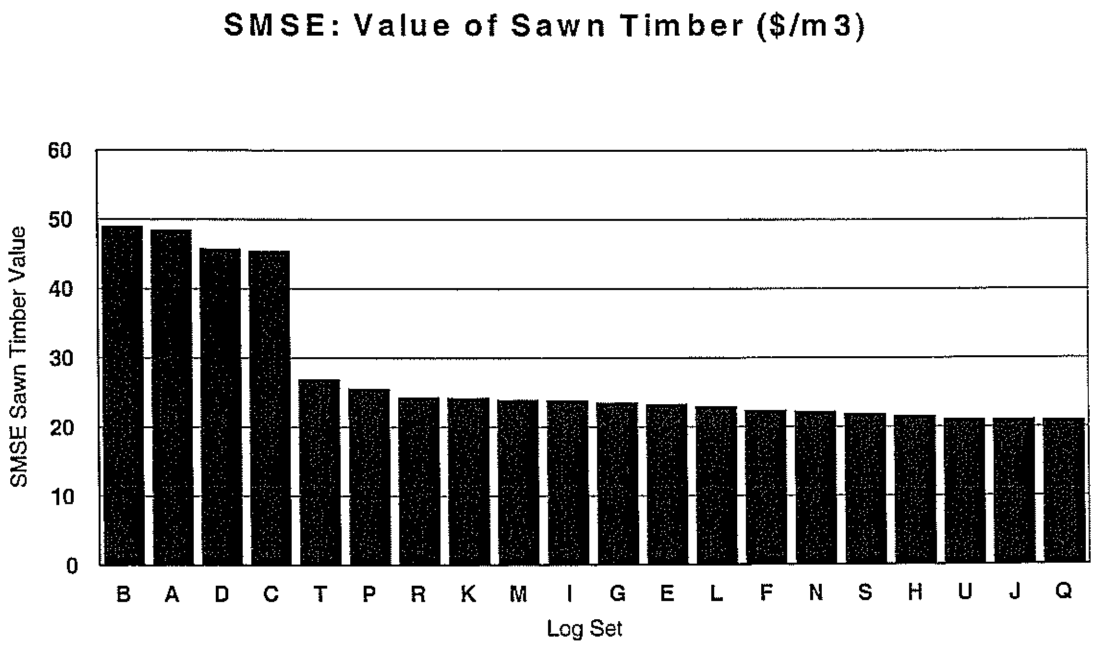

Figure 1: Calculated error in value for each of the log sets

Actual volume of sawn timber by grade

Errors in sawn volume, as indicated by bias and SMSE values (Table 5), were low when compared with the average sawn volume per log of 0.36 m^3. The complex log shape had half the SMSE of the simple log shape. Although inclusion of a measure for sweep gave some reduction in SMSE when compared with straight logs, the effect was not statistically significant. Using ± 2 SMSE as an estimate of the range in prediction errors, volume was predicted to within ±10% using the simple log shape, and ±5% using the complex log shape.

Table 5: Effects of shape and sweep on bias and SMSE in sawn volume

Experimental factor	Level	Bias (m^3)		SMSE (m^3)	
Log Shape	simple	-0.0038	a	0.0212	b
	complex	0.0029	a	0.0107	a
Sweep	straight	-0.0029	a	0.0176	a
	swept	0.0020	a	0.0143	a

Values for each factor followed by the same letter do not differ significantly (p=0.05).

More detail of these results is given in Figure 2. Log sets A, G, H, P, Q (all based on simple truncated cones obtained from length, SED and LED measurements) provided the worst approximation to sawn timber volumes. When a measure for sweep was included (by bending each log at the mid-point) the SMSE compared with that of the straight cones reduced by about 19%. Those logs based on a series of truncated cones (ie several cross-sectional measurements) recorded the lowest SMSEs – they provided better approximations to sawn timber volumes produced by the original set of logs. When comparing the B and A log types (ie series of diameter measurements versus log ends only measurements) a reduction in SMSE of about 52% was recorded. However when the D logs (ie swept series) were compared with the A logs the reduction was not as great at 42%.

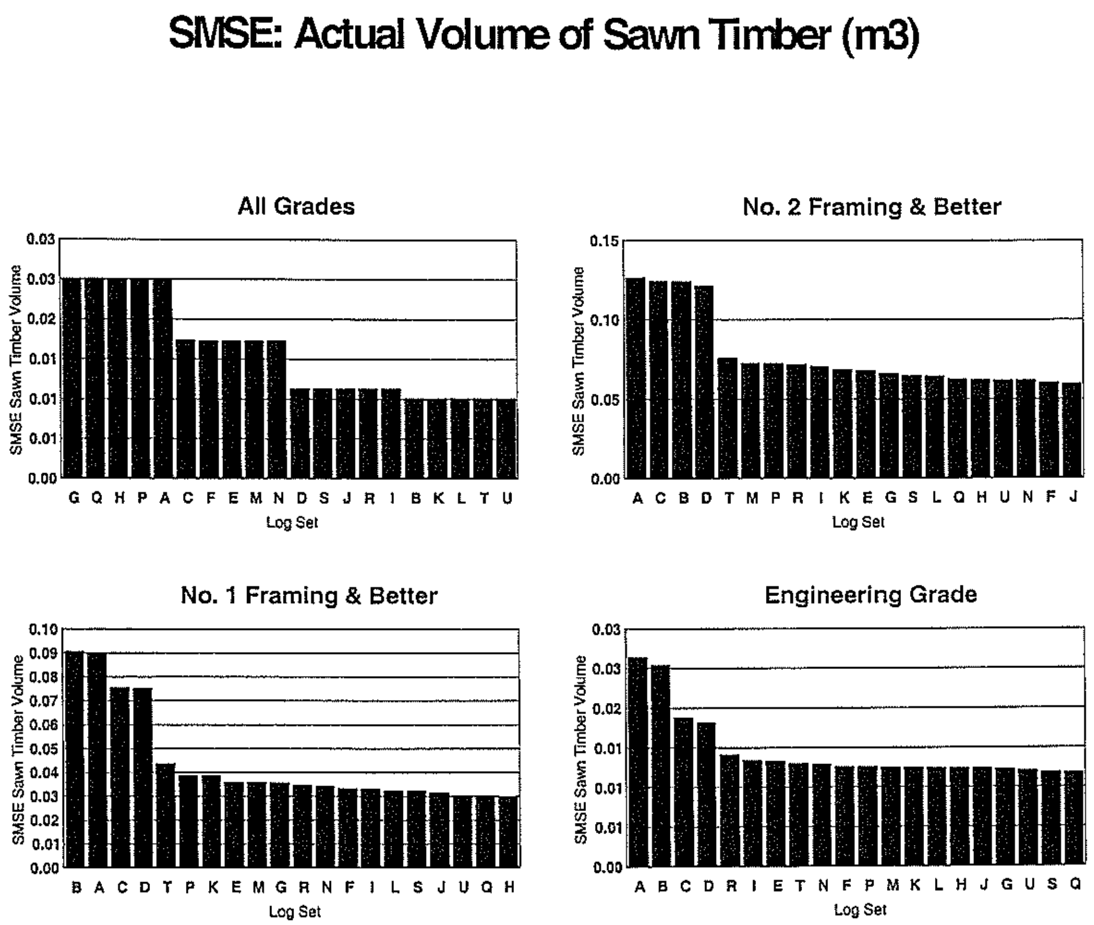

Figure 2: Calculated error in volume for each of the log sets

Percentage volume by grade

Analysis of % timber grade bias (Table 6) and SMSE (Table 7) generally confirmed the results of the timber value analysis. The only experimental factor having a highly significant effect was branch size. Adjusting for maximum branch per log had a large effect on reducing the SMSE, with a further smaller reduction achieved by adjustment for largest branch per whorl (ie every whorl in the log). There was also some evidence of a slight reduction in SMSE for %Eng+1F when log sweep was included.

Overall, even with branch information incorporated in the simulation, the ability to predict timber grade was very poor. The accuracy of timber grade prediction (Eng+1F+2F) was ±(20.6 x2) = 41.1 % when the actual maximum branch/log was supplied, and ±(18.8 x2) = 38.6% when maximum branch/ whorl was added.

Table 6: Effects of experimental factors on bias % sawn volume by timber grade.

Experimental factor	**Level**	**%Eng**		**%Eng+1F**		**%Eng+1F+2F**	
Log Shape	simple	0.7	a	1.0	a	4.5	a
	complex	0.5	a	0.0	a	3.5	a
Sweep	straight	0.6	a	-0.2	a	4.0	a
	swept	0.6	a	1.2	b	4.1	a
No. whorls	unadjusted	0.7	a	0.9	a	4.3	a
	adjusted	0.6	a	0.1	a	3.8	a
Branch diameter	unadjusted	0.0	a	-2.0	a	3.5	a
	adjusted to max branch	0.7	b	0.7	b	3.2	a
	adjusted to max branch per whorl	1.2	c	2.8	c	5.3	a

Table 7: Effects of experimental factors on SMSE % sawn volume by timber grade.

Experimental factor	**Level**	**%Eng**		**%Eng+1F**		**%Eng+1F+2F**	
Log Shape	simple	4.0	a	14.7	a	25.3	a
	complex	4.2	a	14.8	a	25.2	a
Sweep	straight	4.0	a	15.3	a	25.4	a
	swept	4.2	a	14.2	b	25.1	a
No. whorls	unadjusted	4.0	a	14.7	a	25.0	a
	adjusted	4.2	a	14.8	a	25.5	a
Branch diameter	unadjusted	5.3	a	22.3	a	36.4	a
	adjusted to max branch	3.7	b	11.5	b	20.6	b
	adjusted to max branch per whorl	3.2	b	10.4	c	18.8	c

Detailed results of SMSE for each log set are shown in Figure 3.

SMSE: Percentage Volume of Sawn Timber (%)

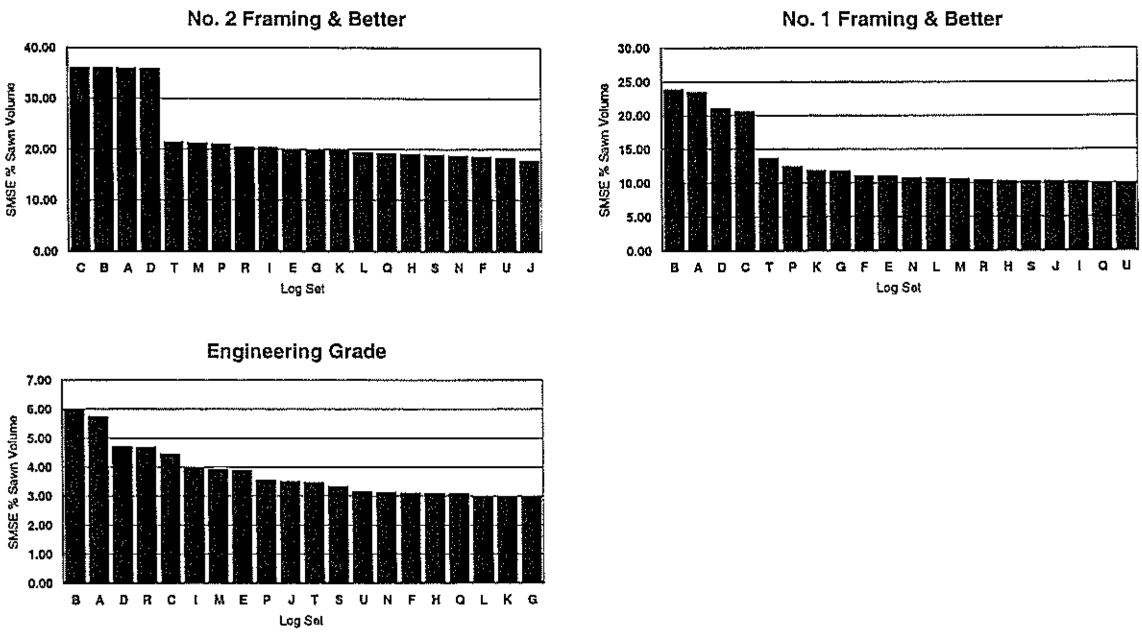

Figure 3: Calculated error in sawn timber conversion percentage for each of the log sets

DISCUSSION AND CONCLUSIONS

Most previous work in predicting sawn timber volume and value has relied on data from sawing studies. For example, SAWMOD (Whiteside, 1982) was based on regression equations derived from sawing studies. Such studies are extremely expensive. Actual logs can also only be sawn once. Saw patterns cannot therefore be directly compared on the same logs.

In this study a relatively new approach was adopted. An attempt was made to simulate branches and log shapes. Sawing of the resulting logs was then simulated using AUTOSAW. This approach potentially offers enormous advantages over the earlier method of sawing actual logs. It is far less expensive, and far more flexible. However, the methodology is still in its infancy, and this should be borne in mind when considering the results.

The measure used in this study to quantify the error between simulated and actual logs, was the SMSE. To some extent, the SMSE provides an inflated estimate of the error, as it includes variation introduced by the sawing simulation process. If a log is re-cut several times (with slightly different starting positions on the head-rig carriage), each cut provides a slightly different value, due to chance interception of branches, etc. This variation is included in the SMSE value. To eliminate this source of variation, individual logs would need to be re-cut several times, and the values averaged. This procedure should be considered in future simulations exercises.

Because the simulations were all based on the same basic set of logs, it was expected that the bias would be close to zero, even for simulation runs which included little individual log information. This generally proved to be the case, and suggests that the simulation exercise itself, including the various methods used to adjust branch size and number, was not a source of significant bias.

Errors in estimating sawn timber volume where found to be halved by incorporating a series of log diameter measurements (in addition to sed and led). However, errors were quite small, even when using only sed and led. They also suggest that a measure for log sweep may improve the volume estimate, although the effect was not large. To quantify this effect more precisely would require more logs, and a wider range of sweep values.

This study confirmed that predicting timber value and grade for individual logs based on external log characteristics is extremely difficult. Regression equations used in SAWMOD, based on earlier sawing studies, used branch index (a measure of the largest four branches per log) and to a lesser extent, log diameter, for predicting visual structural grades. Other variables such as internode index, numbers of whorls per log and sweep, did not prove significant, although internode index was found to be important for predicting clear cuttings grades. These regression equations are relatively poor at predicting timber value for individual logs, although predictions for batches of logs are much better.

In the current simulation study largest branch size per log was by far the most important factor for improving sawn timber value predictions. Some further improvement in prediction was provided by using the maximum branch size per whorl. However, including the number of whorls per log, log sweep or more detailed log shape measurements provided no improvement in prediction.

These results indicate that if measurements of log quality with the Timber Tech caliper included sed, led, length, and largest branch in each whorl, the accuracy of timber grade prediction from AUTOSAW would be ±38.6%. This level of accuracy is unacceptable, as the results would be of little practical value.

This study raises more questions than it answers. If the largest branch per log can explain approximately 50% of the variation in timber value, how can the remaining 50% be explained? Are there any relatively easily measured log characteristics that can be used to significantly improve the predictions (eg, number of branches greater than a certain diameter)? Using log and sawing simulation, it should be possible to answer these questions.

APPENDIX A

Literature Review

Due to the combinatorial nature of the problem, systems analysis and operations research (OR) techniques are applied to aid the decision-making process. To further reduce problem complexity, simplifying assumptions are evidenced in the literature: often, local decisions are sought; stem and log models are reduced to simple geometric forms (eg cylinder or truncated cone); and information relating to quality (branches/knots) is often omitted.

Stem Bucking

The problem of cross-cutting (bucking) stems into logs has received attention since the early 1960s. Solutions to this process have been derived using linear programming (Smith and Harrell, 1961); heuristics (Murphy, 1978); and dynamic programming (DP) (Pnevmaticos and Mann, 1972).

In 1984 Faaland and Briggs extended the bucking problem. Their model simultaneously optimised the bucking of stems into logs, the sawing of logs into flitches, and the edging of flitches into finished dimensions. This was accomplished by integrating the bucking solution proposed by Briggs (1980), the sawing solution proposed by Tejavibulya (1981), and a knapsack formulation for the edging problem. Because of the complex nature of the problem, logs were regular in shape and a live (through and through) sawing pattern was used. Another integrated model that allowed a greater range of sawing patterns was later developed by Reinders and Hendriks (1989). This latter model is simplified by assuming stems to be truncated cones and ignores 'details' such as saw kerf, and quality.

Log Allocation and Sorting
An extensive review of log allocation models is given by Bare et al. (1978). The log sorting problem, which can also be considered a log allocation problem (with competing facilities now defined by the differing processing lines at a given sawmill) has been addressed by Sampson and Fasick (1970).

Log Sawing
Much research effort has focussed on the development of log breakdown and log sawing models. Examples include the simulation models of: Peter and Bamping (1962), Tsolakides (1969), Reynolds (1970), Richards (1973), Pnevmaticos et al. (1974), Garcia (1987), and Todoroki (1990). Other log breakdown models that utilise OR techniques include those of Funck et al. (1993), Funck and Zeng (1995) and Todoroki (1999). These models include DP formulations that simultaneously optimise the log sawing and flitch edging processes. Todoroki extended the simultaneous optimisation to include the board grading process. Funck and Zeng (1995) address board grading with an expert system. However grading is not considered by Funck et al. (1993) as branches are not considered in the log model.

Log breakdown models are distinguished by their simulation capabilities (ie sawing pattern selection, inclusion of sawkerfs, sawing methods, edging methods, and the mix of possible board dimensions) and by their representation of log and defect geometry.

Results from both simulations and actual sawing studies (eg Cown et al., 1984) indicate that the main sources of variation in sawn outturn can be attributed to log geometry, knot distribution, and log breakdown method.

Regressions and Log Variables

In 1982, Whiteside developed a series of multiple regressions describing relationships between log variables and grade/ sawn timber values / log conversion percentages. The regressions were developed as a means to filling knowledge gaps. The important variables of sawlogs identified by Whiteside (1982), Park (1980) and Cown et al (1984) included small end diameter (sed), sweep, defect core diameter (for pruned logs), branch size, and internode lengths.

Log Models

The simplest mathematical forms that have been assumed for stem and/or log models are the cylinder and the truncated (right circular) cone. Although the cylinder has been considered unsuitable for many purposes as it ignores taper (Airth and Calvert, 1973) its intrinsic simplicity has seen its application in the sawing simulation program of Pnevmaticos *et al.* (1974) and Faaland *et al.* (1981). The former computer program could also represent logs as truncated cones. This more generally accepted log form has also been adopted by Richards (1973), Airth and Calvert (1973) and Lewis (1985).

The above forms can be characterised by a functional relationship which exists between diameter and distance from origin. This gives rise to log shapes which are symmetrical about the central log axis, and as a consequence, all are distinguished by circular cross-sections.

However logs are seldom symmetrical. Irregular forms, demonstrating sweep, crook, and areas of swelling, are often the rule rather than the exception. As the limitations of the preceding mathematical forms were recognised, researchers focussed their efforts on developing more realistic representations of logs.

Garcia (1987) represented logs by a series of independent circular cross-sections. These permitted log models to assume a more natural form — demonstrating crook, sweep, taper, bumps, and kinks. Internal defects were also represented. Whorls of branch stubs contained within the defective core of pruned logs were represented by polygons. The model also made provision for representation of the stem pith, which similar to actual stems, can deviate from the central log axis. Shortly afterwards, the log model was altered to allow eccentric logs by introducing elliptical cross-sections (Todoroki, 1988). Later, individual branch descriptions were added to the log model (Todoroki, 1997). The descriptions permitted the representation of both live and dead branches with the former represented by (right circular) cones and the latter represented by a cylinder concatenated to the end of the cone. Each branch could assume any size and spatial orientation and the pith could also deviate from the central axis of the log. A schematic representation of an AUTOSAW log model is shown in Figure 4. The progression of log models from simple mathematical forms is shown in Figure 5.

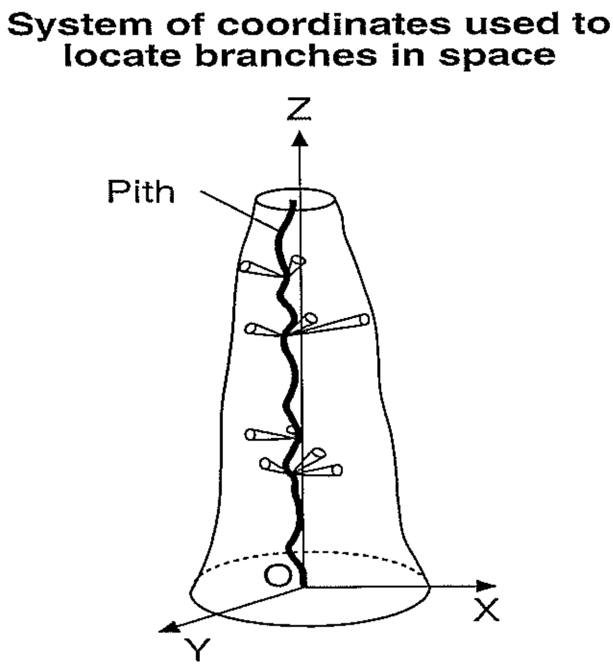

Figure 4: AUTOSAW log model

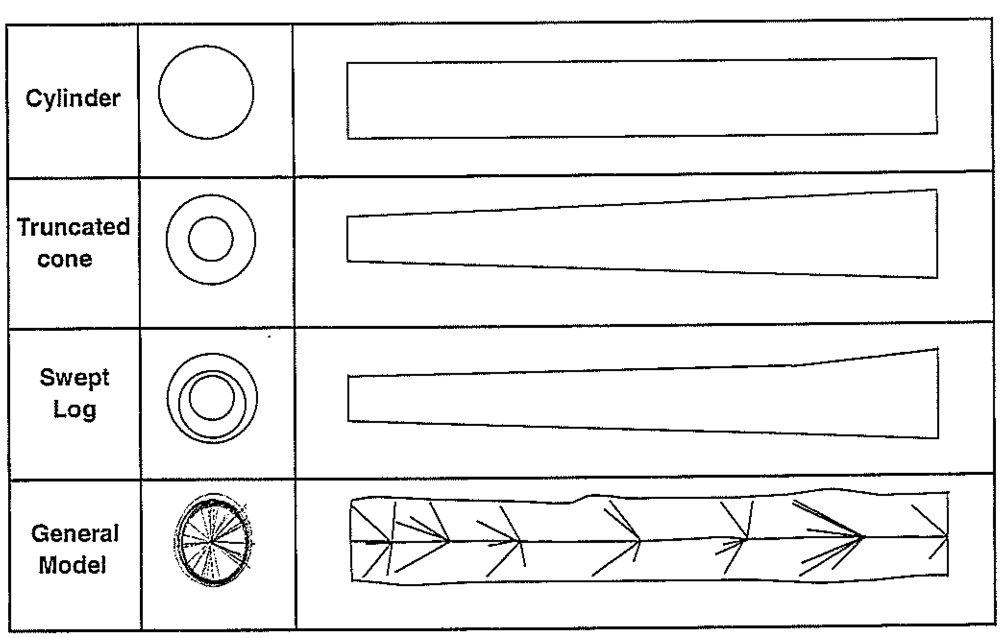

Figure 5: Log models of varying degrees of sophistication

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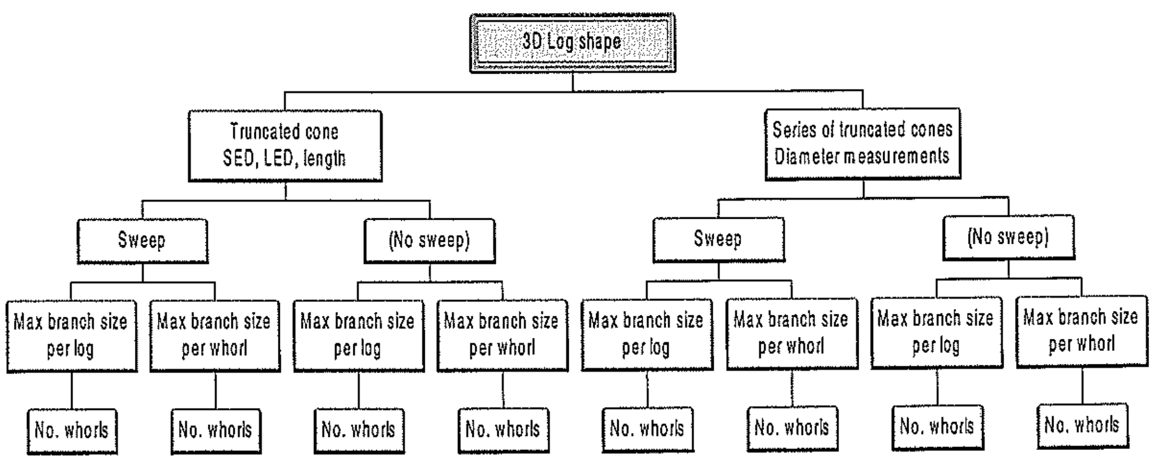
APPENDIX B

Details of Simulated Logs

The original set of 15 logs formed the basis from which a further 4500 virtual logs were generated (see following diagram). Each of the synthesised logs retained some basic log / branch parameters of the original base logs. For example, the 225 logs represented by Ki_j (i = 1..15, j = 1..5) retained some of the log shape characteristics of log Oi (i = 1..15) (ie log Oi was 'straightened' to give log models expressed by a series of truncated cones) and the branch sizes in log Oj (j = 1..15) were scaled to be comparable to those in log Oi.

Variables for Analysis and Comparison with Actual Log



The nomenclature and main characteristics of the synthesised logs are summarised below:

Oi: i = 1..15

Virtual 3D logs reconstructed from the original set of logs obtained from Kaingaroa. Each log cross-section is represented by an ellipse (not necessarily centred about the origin) – hence these logs have irregular form (in addition to taper and sweep, kinks and bumps can be described)

Ai_j: i,j = 1..15

Regularly shape logs described by a truncated cone) – uses SED (where SED assigned as min{semi-minor diameter, semi-major diameter) and LED (= min of 2 diameters) of log Oi and branching model in log Oj. Branch lengths in log Ai_j are adjusted so that they meet the external log profile.

Bi_j: i,j = 1..15

Log shape is defined as a series of truncated cones, ie sectional diameter measurements, – using {min} diameter measurements of log Oi and branching model in log Oj. Branches in log Bi_j are adjusted so that they meet the external log profile.

Ci_j: i,j = 1..15

Each log Ai_j is bent at the mid-point (ie an extra sections is inserted). The amount of bend in Ci_j s equal to the sweep recorded for Log Oi (refer Table 1).

Di_j: i,j = 1..15

Each log Bi_j is bent at the mid-point (ie an extra sections is inserted). The amount of bend in Di_j is equal to the sweep recorded for Log Oi (refer Table 1).

Ei_j: i,j = 1..15

The branch sizes in Ci_j are scaled by a factor given by the ratio of the largest branch size in log Oi over the largest branch size in Log Oj.

Fi_j: i,j = 1..15

The branch sizes in Ci_j are scaled by a factor given by the ratio of the largest branch size in a whorl selected from log Oi over the largest branch size in Log Oj.

Gi_j: i,j = 1..15

The branching patterns of Ei_j are applied to the log shapes given by Ai_j.

Hi_j: i,j = 1..15

The branching patterns of Fi_j are applied to the log shapes given by Ai_j.

Ii_j: i,j = 1..15

The branching patterns of Ei_j are applied to the log shapes given by Di_j.

Ji_j: i,j = 1..15

The branching patterns of Fi_j are applied to the log shapes given by Di_j.

Ki_j: i,j = 1..15

The branching patterns of Ei_j are applied to the log shapes given by Bi_j.

Li_j: i,j = 1..15

The branching patterns of Fi_j are applied to the log shapes given by Bi_j.

Mi_j: i,j = 1..15

The number of whorls in log Ei_j is altered (by adding/removing randomly selected whorls from log Ei_j) to reflect the number of whorls in log Oi.

Ni_j: i,j = 1..15

The number of whorls in log Ei_j is altered (by adding/removing randomly selected whorls from log Ei_j) to reflect the number of whorls in log Oi.

Pi_j: i,j = 1..15

The number of whorls in log Gi_j is altered (by adding/removing randomly selected whorls from log Gi_j) to reflect the number of whorls in log Oi.

Qi_j: i,j = 1..15

The number of whorls in log Hi_j is altered (by adding/removing randomly selected whorls from log Hi_j) to reflect the number of whorls in log Oi.

Ri_j: i,j = 1..15

The number of whorls in log Ii_j is altered (by adding/removing randomly selected whorls from log Ii_j) to reflect the number of whorls in log Oi.

Si_j: i,j = 1..15

The number of whorls in log Ji_j is altered (by adding/removing randomly selected whorls from log Ji_j) to reflect the number of whorls in log Oi.

Ti_j: i,j = 1..15

The number of whorls in log Ki_j is altered (by adding/removing randomly selected whorls from log Ki_j) to reflect the number of whorls in log Oi.

Ui_j: i,j = 1..15

The number of whorls in log Li_j is altered (by adding/removing randomly selected whorls from log Li_j) to reflect the number of whorls in log Oi.