CONCEPTUAL METHOD FOR COMPARING YIELD FROM CURVE-SAWN AND STRAIGHT-SAWN LOGS

C. L. TODOROKI

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

and E. M. RÖNNQVIST

Linköping University, Linköping, Sweden

(Received for publication 8 April 1997; revision 16 June 1998)

ABSTRACT

When straight sawing technology is used, yields from irregularly-shaped (swept) logs are lower than those from comparable unswept logs. The greater the sweep, the greater the anticipated yield loss. Developments in curve-sawing technology may improve yields from swept logs; volume increases of 3%–20%, and board length increases exceeding 20% have been suggested. The destructive nature of the sawing process precludes direct verification of such claims.

A method has been developed to allow simulation of conceptual curve-sawing using a straight-sawing simulation system. Curve-fitting and data transformation are used to remodel a swept log as its "straightened" counterpart. This "log metamorphosis" was applied to a sample of 40 log models constructed from measurements of actual logs and selected to cover a range in size, shape, and quality. Sawing simulations were performed before and after log metamorphosis in order to compare straight- and curve-sawn yield. Results were variable, but increases in estimated recoveries fell within the assumed ranges reported for actual curve-sawing.

Keywords: AUTOSAW; curve/sweep sawing; sawing simulation; spline.

INTRODUCTION

Effect of Log Sweep

Not all logs are straight. In fact very few are "straight" in the true mathematical sense of the word. Most logs exhibit a gradual diminution of diameter with height, known as taper; they may also be bent or curved. Curvature of a log, commonly described as sweep, is known to cause yield losses (Dobie 1964; Brown & Miller 1975; Dobie & Middleton 1980; Cown *et al.* 1984). Dobie & Middleton derived a general rule of thumb that for each 0.1 increase in the ratio of sweep (measure of curvature or bend in a log) to small-end diameter, a yield reduction of about 7% could be expected. A slightly smaller value (5%) was derived by Cown *et al.* Conventional sawing equipment that breaks the log down with a series of straight saw cuts was used in all the studies listed above. It is the combination of straight sawing and irregularly shaped logs that often results in substantial yield reduction.

Curve Sawing

When all relevant measures such as good bucking strategy together with true shape scanning, thin-kerf sawing, and integrated log breakdown optimisation have been exploited, further improvements may still be achieved through the use of curve/sweep sawing technology. The first recorded patent for a truly curved saw dates back to 1907. Curve-sawing currently appears to be undergoing a resurgence in popularity and new techniques are being developed (McInvale 1995).

Three methods of curve sawing with respect to log shape have been identified (Wang *et al.* 1992): sawing parallel to the centre line, parallel to the concave side, and parallel to the convex side of the log. The first method was patented by N.Lindstrom in 1979 and is used in sawmills in Scandinavia. The second method, patented by Hasenwinkle *et al.* (1987), has been implemented by the Weyerhaeuser Company at sawmills in the United States. Kenyon (1978) patented apparatus that, whilst also designed to minimise the impact of knot stubs and other surface irregularities, allows curve-sawing parallel to either side of the log. A diagrammatic comparison of the effects of curve-sawing and straight-sawing of a swept log is shown in Fig. 1(a) and (b). Curve-sawing of an S-shaped log gives a greater yield differential (Fig. 1(c) and (d)).

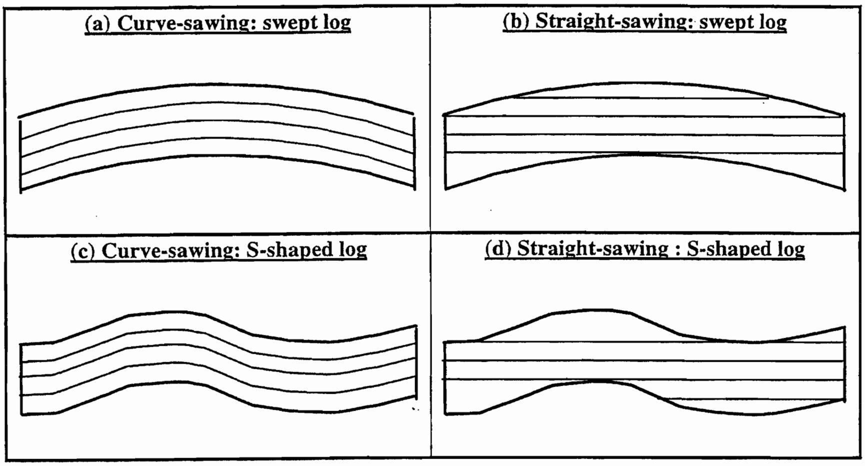

FIG. 1–Diagrammatic comparisons between curve- and straight-sawing.

The curve-sawn product is initially bent. "However, the boards straighten relatively easily because curve sawing preserves the wood's natural grain. This makes the technology useful for both green-lumber producers and mills using kiln drying" (Consolidated Sawmill Manufacturing International 1994).

In addition to maintenance of the structural integrity of the wood, the following benefits have been reported:

- Timber yield increases
- Longer boards
- Stronger boards

Anttila (1993) claimed yield increases of 10–20% depending on the sweep/curve of the raw material. A more conservative estimate of 3–10% was obtained by McInvale (1993) who concluded that "The key factors that influence improved recovery are log size and sweep. The smaller the log and the greater the sweep, the higher the recovery improvement". Wang *et al.* (1992) cited improvements of 16, 8, and 4% for logs with average top diameters of 4.4, 5.5, and 7.1 inches (112, 140, 180 mm) respectively. Yield increases arise because "Curve/ sweep sawing allows you to fit a 'bigger' sawing pattern in the same log, because you can consider any logs with sweep up to your sweep/curve limit as 'straight'!" (Anttila 1993). Cuts following the shape of the log maximise the length of the outer boards. Increases in board lengths of over 20% have been reported (Anttila 1993). As curve-sawing follows the grain, cross-grain (which causes downgrade in lumber strength) is virtually eliminated. Increases in board strength of 15–20% have been reported. Another benefit is straighter dried lumber. The main drawbacks to curve-sawing are the high capital cost associated with the curve-sawing system (approximately US$2,000,000) and the increase in saw costs which are estimated to be approximately double that of saws for straight-sawing.

Verification of the benefits claimed for curve-sawing is difficult due to the destructive nature of the sawing process. Once sawn, a log cannot be reconstituted. Furthermore, finding the equivalent straight-log counterpart of a swept log is not a trivial task since variability in size, shape, and (internal) quality results from innumerable biological processes. These factors preclude direct comparison of straight-sawn and curve-sawn yields. Conceptualisation and computer sawing simulation offer a theoretical approach whereby these practical difficulties can be overcome.

Computer Sawing Simulation Systems

Numerous sawing simulation and log breakdown models have been developed (Tejavibulya 1981; Lewis 1985; Occeña & Tanchoco 1988; Todoroki 1990; Funck *et al.* 1993). All have applied straight-sawing techniques—the differences being in type and range of sawing patterns; sawing, edging, and trimming methods; mix of possible board sizes; representation of the log models; and ability to include internal log defects. Curve-sawing simulation appears to have received little attention. One system, which also simulates straight-sawing, is SAWSIM® (HALCO Software Systems Ltd). This has been examined by Wang (1989), Hards (1989), and Sargeant (1994) who wrote "the sawing action attempts to follow the 'outside' curve (full taper sweep sawing) or the centre line (split taper) of the log or cant. The system will choose the higher valued taper alignment. Opening face positions for the full-tapered alignment are evaluated at 0.25" increments, starting from the edge of the cant. The system will follow the variable sweep and not an arc. It is assumed there is no leading or trailing ends that will be straight sawn". No further explanation of the computational procedure or other detail was presented.

Curve-sawing Simulation

Sawing simulation clearly has potential for notional evaluation of the effect of curve-sawing. Simulation of curve-sawing practices can be achieved in two ways. One (similar to the approach assumed in SAWSIM®) is to mimic actual curve-sawing practices and expand the straight-sawing simulator's capabilities to permit the sawcuts to follow the log's curvature, together with a board "straightening" operation prior to timber yield evaluation. An alternative is to "straighten" the log before straight-sawing simulation. This latter approach (denoted here as "Conceptual Curve-sawing") is motivated by the concept that curve-sawn logs can be considered as being "straight" since the curvature of the saw follows that of the log. Although both approaches (illustrated schematically in Fig. 2) are mathematically equivalent, the latter is less complex both to formulate and to solve. Moreover, it offers a more readily accessible method for assessing curve-sawn yields, due to the abundance of straight-sawing simulators. The procedure described here and used in a study comparing yields from straight- and curve-sawing simulation is believed to be unique at the time of writing.

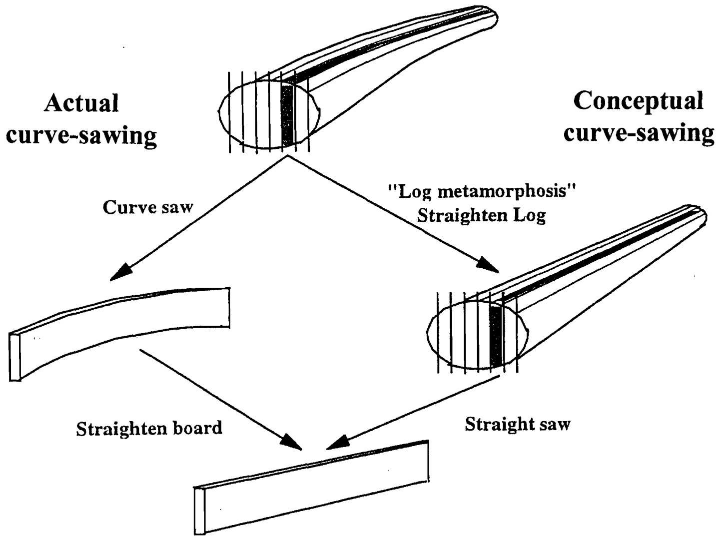

FIG. 2–Schematic diagram of two approaches to curve-sawing simulation

METHOD

Conceptual curve-sawing was performed in two stages: log metamorphosis, i.e., the process of transforming a three-dimensional (3-D) log model (including internal defects) to its straightened counterpart, followed by log breakdown simulation.

The process of log metamorphosis involved the application of a three-step procedure:

Step 1: Derivation of an approximating function (based on cubic smoothing splines) which describes the curvature of the log.

Step 2: Introduction of a 3-D co-ordinate system with cylindrical co-ordinates where the main (nonlinear) axis is defined by the approximating function and the other two axes are cylindrical parts around the central curve.

Step 3: Linear transformation of data to map all points in the original 3-D system into the new co-ordinate system.

Each original log model comprised a number of elliptical cross-sections, spatially located with measured offsets relative to one another. A function connecting these cross-sectional centres was defined by interpolation (Step 1). This approximating function was mathematically smoothed and then subjected to linear transformation to derive an equation describing a corresponding straight line (Steps 2 and 3). The transformation function (Step 3) was applied to all points describing the log (including internal defects such as branches and pith).

The approximating function of Step 1 was based on cubic smoothing splines (De Boor 1978) which have been used in the determination of volume from sectional measurements of tree stems. Goulding (1979) applied a natural cubic spline curve to cross-sectional area measurements along the stem of the tree and derived stem volume from the integral of the curve. He found that "... some combinations of malformation and location of measurements cause the spline curve to estimate interpolated diameters less than satisfactorily over parts of the stem" and concluded that the curve is "inappropriate when applied to those profiles of malformed stems with rates of taper which abruptly change". Goulding suggested that

> "With some heavily malformed trees, a form with a discontinuous first derivative approximated by piecewise line segments may be more appropriate. Alternatively separate spline curves can be fitted to the data on either side of the malformed section and the first derivatives estimated from the spline curves at the junction. A further spline curve can be fitted over the malformed section using these first derivatives at the end points. The resultant composite curve would have a continuous first derivative over the whole tree, but have discontinuities (usually large) in the second derivative at the junction points."

Smoothing splines have also been found to be appropriate for noisy data. A smoothing spline can be formulated as a constrained minimisation problem (Dierckx 1993) whose objective is to obtain a smooth curve with minimum departure from the given data. The current study included a further constraint which preserved the sinuosity in log shape (T.Allsopp, University of Auckland, unpubl. data).

Because the log metamorphosis process preserved cross-sectional radii, distances between adjacent cross-sectional centres, and internal defect sizes, a straight-log counterpart of the original swept log was created and direct yield comparisons could be made.

A sample of 40 "logs", three-dimensional reconstructions of actual pruned *Pinus radiata* D.Don butt logs that had been intensively measured (both externally and internally), was used in this study. The models, each nominally 4.8 m long, were selected to cover a range of size, shape, and qualities. Small-end diameter (s.e.d.) ranged from 277 mm to 579 mm, the degree of sweep from 3 mm/m (minimal) to 12 mm/m (extreme), and defect core size from 198 to 362 mm. Log sample statistics are summarised in Table 1 and a scatter diagram of log sweep and s.e.d. is presented in Fig. 3. Summary statistics of each of the reconstructed logs are given in Appendix 1. It is important to note that these statistics provide an indicative, rather than definitive, measure of log size, shape, and quality, just as the combination of height, weight, and IQ score provides only a partial description of a person.

All sawing simulations in this study were performed with the AUTOSAW system (Todoroki 1990) which utilises the full three-dimensional log description (including internal

TABLE 1–Summary of general characteristics of the 40-log sample

Log	s.e.d. (mm)	Defect core (mm)	dbh (mm)	Sweep (mm/m)	Taper (mm/m)	Volume (m^3)
Average	420	289	459	7	18	0.79
Std dev.	68	36	75	3	6	0.24
Minimum	277	198	311	3	8	0.36
Maximum	579	362	643	12	36	1.46

s.e.d. = small-end diameter
dbh = diameter at breast height (1.4 m)

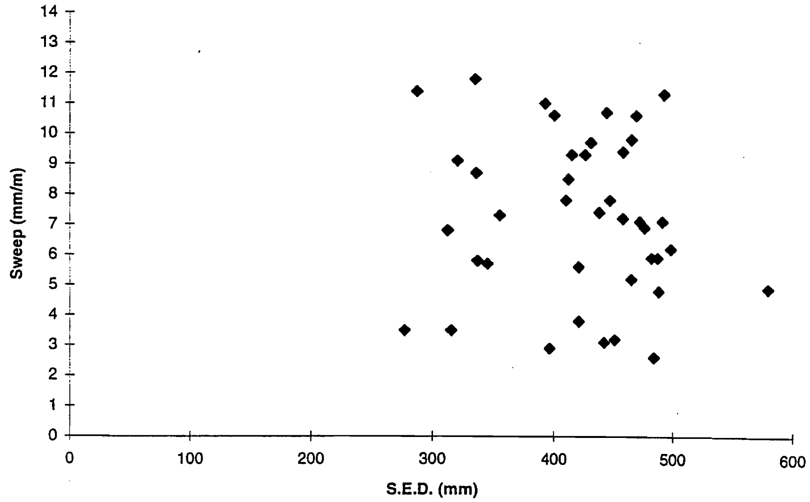

FIG. 3–Sweep and small-end diameter in the 40-log sample

defects) as input. Comparisons between actual and simulated timber grade yield (using three-dimensional log models constructed from measurements of those logs physically sawn and simulating sawing parameters and procedures used at the sawmill) have shown this system to be reliable (Park 1987, 1989; Park & Todoroki 1992a, b).

Two sets of sawing simulations were performed. The first used the sample of 40 log models described above. The second set used log models, each obtained from the original set by log metamorphosis. For both sets, log models were positioned with "horns down" and identical sawing parameters were used in the simulated breakdown of each log into boards.

Output from each simulation consisted of a list of dimensioned and graded boards from which yield was calculated. For each log the predicted timber volume yield increase associated with conceptual curve-sawing, ΔV_i, $i = 1..40$, was calculated as:

$$\Delta V_i = 100 \times \frac{(V_i^C - V_i^S)}{V_i^S} \qquad i = 1..40$$

where V_i^C and V_i^S denote the volume yields obtained from simulations using metamorphosed and original log models (corresponding to conceptual curve- and straight-sawing methods) respectively.

In lieu of a pricelist, timber grades were weighted, the highest weighting being assigned to clears grade and the lowest to box grade (Table 2). This procedure generated relative rather than actual values. The predicted percentage increase in value, ΔP_i, was determined in a manner similar to that for ΔV_i.

TABLE 2–Grade weightings used in simulations

Grade	Description	Weighting
Clear	Board contains no defects	1.0
Clear one face	Board free of defects on one face	0.9
Shop	70% of the board in clear lengths of at least 1.0 m	0.8
Factory	50% of the board in clear lengths of at least 0.6 m	0.7
Knotty	Board contains knots but no pith	0.6
Knotty with pith	Board contains pith	0.5

NUMERICAL RESULTS

Volume yields (V_i^S and V_i^C), relative timber values (P_i^S and P_i^C), and percentage increases (ΔV_i and ΔP_i) for each log (i = 1..40) are given in Appendix 2.

A paired T-test showed that yields resulting from conceptual curve-sawing were significantly higher ($p < 0.01$) than those from straight-sawing. The average increase in sawn timber volume was 5.7 ± 5.4%. The highest increase for an individual log was 21.4%. Increase in volume yield was plotted against log sweep (Fig. 4). Although the points were scattered (due to the wide variability in log size and shape indicated in Table 1) greater yield increases tended to be associated with logs having greater sweep.

The total number of boards obtained in each length class (± 0.2 m) is given in Fig. 5. In the 4.8-m class (i.e., full-length boards) obtained from the 40-log sample before and after log metamorphosis there were 556 and 676 boards respectively.

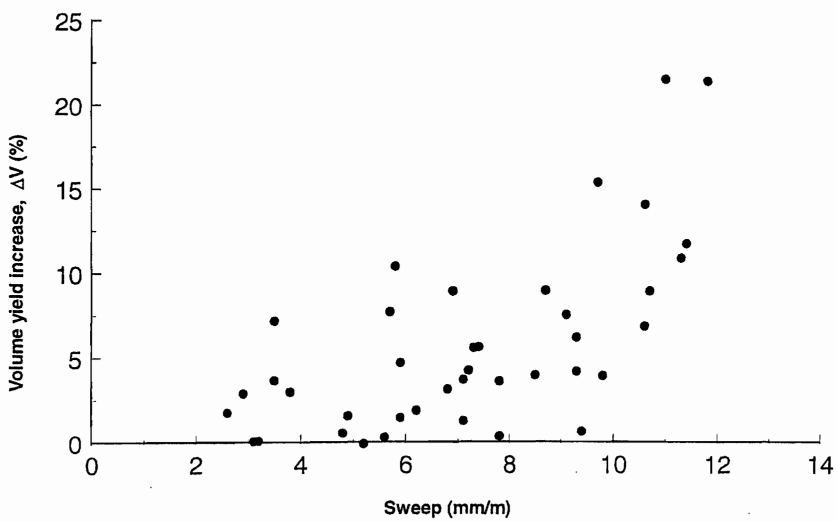

FIG. 4—Volume yield increases associated with conceptual curve-sawing and sweep in the 40-log sample

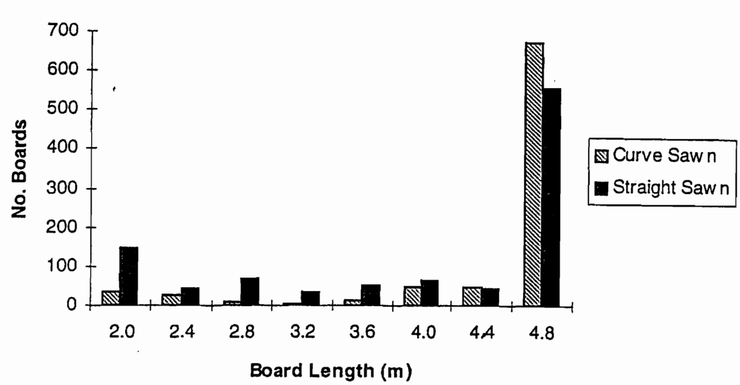

FIG. 5—Board lengths obtained from simulated straight- and conceptual curve-sawing of the 40-log sample

Comparisons of relative value yield showed an average increase of 5.8 ± 6.6%, derived mainly from longer clear lengths cut from the outer regions of each log. The maximum individual log value was 27.6%.

DISCUSSION

Working on the assumption that results obtained using the new conceptual method are indicative of actual curve-sawn yields, volume and value yield improvements and board length increases are likely to be achieved from curve-sawing swept logs. The variability demonstrated by the results is consistent with the observed irregularity of log form and internal defect structures of the sample. In addition to sweep, factors such as crook, taper, areas of swelling, cross-sectional ovality, defect distribution, size, and shape all influence log shape and quality, and will therefore affect sawn timber yield. All but four of the 25 logs in the sample with sweep greater than 6 mm/m, showed volume yield increases greater than 3% (upper limit 21%) when curve-sawn by this method (Appendix 2). All four exceptions had a high degree of taper (22, 25, 30, 36 mm/m). When sweep was less than 6 mm/m, five of the remaining logs showed increases exceeding 3% (upper limit 10%). Taper in these logs ranged from 10 to 20 mm/m.

Validation of results derived from conceptual curve-sawing is difficult, and would require new techniques in data acquisition to enable accurate reconstruction of log and internal defect models. After curve-sawing, measurement of board and defect locations is more difficult than after straight-sawing since the assumption that they lie in the same plane is no longer valid.

For swept logs, curve-sawing is an important alternative to straight-sawing. Benefits associated with curve-sawing can be assessed with the aid of computer simulation tools. Since the vast majority of log breakdown simulation systems available today apply conventional "straight-sawing" techniques, the method presented here provides scope for use of these conventional tools for curve-sawing assessments, and removes the need to develop further specialised software.

CONCLUSIONS

Using a new method described as "log metamorphosis", a three-dimensional description of a swept log can be transformed to its "straightened" counterpart. Straight-sawing simulation can then be used to examine the effects of conceptual curve sawing. In a study of a 40-log sample, the calculated mean volume yield increase of 6% (upper limit 21%) and the 22% increase in the number of full-length boards associated with conceptual curve-sawing were found to be consistent with assumed benefits claimed for actual curve-sawing.

ACKNOWLEDGMENTS

The authors wish to thank Toby Allsopp, a fourth-year engineering student at Auckland University, for transforming the data (by log metamorphosis) in preparation for the sawing simulations. Alexandra Hawke, Louw Van Wyk, and Ruth Gadgil (New Zealand Forest Research Institute) are respectively thanked for the statistical analysis of the data, discussions on curve-sawing practices, and arrangement of and amendments to this text.

REFERENCES

ANTTILA, I 1993: Why curve sawing? Is there a benefit for you? Proceedings of SawTech '93, San Francisco, California, 14–16 October.

BROWN, A.G.; MILLER, R.G. 1975: Effect of sweep on sawn recovery from radiata pine logs. *Australian Forest Research 7(1)*: 29–39.

COWN, D.J.; McCONCHIE, D.L., TRELOAR, C. 1984: Timber recovery from pruned *Pinus radiata* butt logs at Mangatu: Effect of log sweep. *New Zealand Journal of Forestry Science 14(1)*: 109–123.

CONSOLIDATED SAWMILL MANUFACTURING INTERNATIONAL 1994: Throwing mills a curve: A renaissance technology. *Canadian Wood Products, March/April*: 10–11.

De BOOR, C. 1978: "A Practical Guide to Splines". Springer-Verlag, New York.

DIERCKX, P. 1993: "Curve and Surface Fitting with Splines". Oxford University Press, New York.

DOBIE, J. 1964: Log sweep and lumber production in the B.C. Interior. *British Columbia Lumberman 48(10)*: 34–37.

DOBIE, J.; MIDDLETON, G.R. 1980: Lumber yields from sweepy lodgepole pine. *The Forestry Chronicle 56(2)*: 66–67.

FUNCK, J.W.; ZENG, Y.; BRUNNER, C.C.; BUTLER, D.A. 1993: SAW3D: A real shape log breakdown model. *Proceedings of the 5th International Conference on Scanning Technology and Process Control for the Wood Products Industry, Atlanta, GA, USA, 25–27 October.*

GOULDING, C.J. 1979: Cubic spline curves and calculation of volume of sectionally measured trees. *New Zealand Journal of Forestry Science 9(1)*: 89–99.

HARDS, J. 1989: Curve sawing. Pp.117–128 *in* Middleton, G.R. (Ed.) "Advances in Sawmill Technology". *FRDA Report 102.*

HASENWINKLE, E.D.; WISLOCKER, F.; BLICKENDERFER, C. 1987: Variable curve linebar. US Patent 4,633,924. US Patent Office, Washington, DC.

KENYON, A. 1978: Apparatus for sawing and for controlling the sawing process. US Patent 4,127,044 US Patent Office, Washington, DC.

LEWIS, D.W. 1985: Sawmill simulation and the Best Opening Face System: A user's guide. *USDA Forest Service, Madison, WI. General Technical Report FPL 48.*

McINVALE, W. 1993: Curve sawing technology and benefits. *Timber Processing, September*: 14–19, 31.

———1995: The implications of curve sawing and where it is headed. Proceedings of the Wood Technology Clinic and Show, Portland, OR.

OCCEÑA, L.G.; TANCHOCO, J.M.A. 1988: Computer graphics simulation of hardwood log sawing. *Forest Products Journal 38(10)*: 72–76.

PARK, J.C. 1987: SEESAW: A visual sawing simulator, Part 1: Data, methods, and program evaluation. Pp. 97–106 *in* Kininmonth, J.A. (Comp.) "Proceedings of the Conversion Planning Conference". *New Zealand Ministry of Forestry, FRI Bulletin No.128.*

———1989: Comparison, via the SEESAW simulator, of three sawing systems for pruned logs. *New Zealand Journal of Forestry Science 19(1)*: 54–67.

PARK, J.C.; TODOROKI, C.L. 1992a: AUTOSAW sawing simulator & the pruned resource: Computers track pruned log to timber grade. *New Zealand Forest Industries 23(2)*: 19–20.

———1992b: AUTOSAW & the pruned resource: Further applications and development. *New Zealand Forest Industries 23(4)*: 30, 32.

SARGEANT, T. 1994: A case study in sawmill simulation. Supplementary material (HALCO Software Systems Ltd) to Proceedings of Workshop "Improving Your Sawing Patterns". Ministry of Forestry & FRI, Rotorua, 8 August.

TEJAVIBULYA, S. 1981: Dynamic programming sawing models for optimizing lumber recovery. Ph.D. dissertation, College of Forest Resources, University of Washington, Seattle, WA.

TODOROKI, C.L. 1990: AUTOSAW system for sawing simulation *New Zealand Journal of Forestry Science 20(3)*: 332–348.

WANG, S.J 1989: Curve sawing, cant optimization, and log rotation. Pp.96–116 *in* Middleton, G.R. (Ed.) "Advances in Sawmill Technology". *FRDA Report 102.*

WANG, S.J.; MUNRO, B.D.; GILES, D.R.; WRIGHT, D.M. 1992: Curve sawing performance evaluation. *Forest Products Journal 42(1)*: 15–20.

APPENDIX 1

STATISTICS OF THE 40 LOGS USED IN THE STUDY

Log	s.e.d. (mm)	Defect core (mm)	dbh (mm)	Sweep (mm/m)	Taper (mm/m)	Volume (m^3)
1	277	255	318	3.5	20	0.36
2	287	235	311	11.4	21	0.37
3	312	198	344	6.8	16	0.43
4	314	230	333	3.5	10	0.40
5	320	259	370	9.1	19	0.47
6	334	288	364	11.8	18	0.49
7	335	270	378	8.7	15	0.49
8	336	276	348	5.8	11	0.46
9	344	256	366	5.7	13	0.49
10	354	234	379	7.3	16	0.54
11	393	276	401	11.0	13	0.64
12	396	318	413	2.9	13	0.64
13	400	283	417	10.6	14	0.63
14	410	326	493	7.8	36	0.84
15	411	276	460	8.5	24	0.75
16	415	311	492	9.3	28	0.83
17	420	309	446	3.8	11	0.73
18	421	247	493	5.6	21	0.83
19	426	308	444	9.3	14	0.73
20	431	322	460	9.7	15	0.78
21	439	268	523	7.4	26	0.92
22	441	301	479	3.1	17	0.83
23	443	305	488	6.9	8	0.86
24	444	301	482	10.7	17	0.83
25	447	320	491	7.8	17	0.87
26	451	286	503	3.2	21	0.92
27	452	229	500	9.4	25	0.92
28	455	362	507	7.2	26	0.93
29	463	336	504	9.8	22	0.92
30	464	336	499	10.6	16	0.90
31	466	310	509	5.2	21	0.95
32	472	291	515	7.1	22	0.94
33	479	329	509	5.9	14	0.97
34	482	283	511	5.9	24	0.97
35	483	318	519	4.8	15	0.96
36	484	300	511	2.6	19	0.96
37	491	313	558	7.1	25	1.10
38	492	299	517	11.3	11	0.98
39	493	337	546	6.2	30	1.11
40	579	251	643	4.9	26	1.46

APPENDIX 2

VOLUME AND VALUE YIELDS FROM CONCEPTUAL CURVE- AND STRAIGHT-SAWING SIMULATIONS

Log No.	Volume (10^{-2}×m^3)		Increase (%)	Relative value		Increase (%)
i	V_i^C	V_i^S	ΔV_i	P_i^C	P_i^S	ΔP_i
1	20.66	19.28	7.16	12.40	11.79	5.11
2	22.03	19.73	11.66	14.16	12.83	10.35
3	26.21	25.42	3.11	17.51	17.96	–2.51
4	25.30	24.41	3.65	16.58	15.22	8.87
5	27.98	26.03	7.49	18.43	17.56	4.98
6	29.71	24.49	21.31	19.05	14.93	27.55
7	30.43	27.94	8.91	20.07	18.71	7.25
8	29.67	26.89	10.34	17.86	15.72	13.61
9	30.70	28.51	7.68	20.50	19.09	7.37
10	34.66	32.84	5.54	25.76	23.90	7.78
11	42.82	35.27	21.41	27.94	23.64	18.20
12	42.55	41.36	2.88	28.18	26.88	4.82
13	40.19	35.26	13.98	29.52	23.32	26.58
14	49.18	49.02	0.33	35.69	35.78	–0.23
15	45.67	43.94	3.94	34.73	33.36	4.11
16	51.39	48.41	6.16	42.92	37.34	14.94
17	49.25	47.83	2.97	35.24	35.42	–0.50
18	51.74	51.60	0.27	42.43	41.03	3.41
19	47.43	45.54	4.15	35.34	36.13	–2.19
20	50.71	43.98	15.30	35.36	30.57	15.69
21	56.74	53.73	5.60	41.99	41.57	1.02
22	52.78	52.76	0.04	39.62	39.66	–0.11
23	58.90	54.09	8.89	45.65	41.24	10.70
24	58.90	54.09	8.89	45.65	41.24	10.70
25	56.15	54.21	3.58	37.91	40.66	–6.77
26	59.83	59.79	0.07	48.02	46.62	3.01
27	57.77	57.42	0.61	46.82	48.02	–2.50
28	58.08	55.74	4.20	39.00	37.51	3.96
29	59.40	57.17	3.90	44.54	42.06	5.88
30	60.08	56.24	6.83	41.03	39.43	4.07
31	62.15	62.22	-0.11	50.14	46.86	6.99
32	59.75	59.01	1.25	44.34	43.15	2.75
33	64.21	61.35	4.66	44.98	45.46	–1.05
34	61.33	60.46	1.44	43.79	45.04	–2.78
35	62.74	62.41	0.53	43.69	44.64	–2.12
36	61.54	60.48	1.75	45.09	44.05	2.35
37	71.73	69.19	3.67	53.75	52.40	2.58
38	67.92	61.29	10.82	53.14	45.85	15.89
39	70.59	69.29	1.88	50.34	50.96	–1.22
40	97.88	96.37	1.57	80.70	78.80	2.41

V_i^C = volume yield associated with conceptual curve-sawing simulation of log i
V_i^S = volume yield associated with straight-sawing simulation of log i
ΔV_i = percentage increase in volume yield of log i associated with conceptual curve-sawing
P_i^C = relative value yield associated with conceptual curve-sawing simulation of log i
P_i^S = relative value yield associated with straight-sawing simulation of log i
ΔP_i = percentage increase in value yield of log i associated with conceptual curve-sawing