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Effect of edging and docking methods on volume and grade recoveries in the simulated production of flitches

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Summary — This paper describes edging procedures that have been adapted for use in the pruned log sawing simulation system, AUTOSAW, developed at the Forest Research Institute, New Zealand. Automated sawing simulations were performed on a sample of 20 pruned logs using a standardised sawpattern. These simulations produced a total of 483 flitches of which 221 flitches required edging/docking operations to be applied. Methods were developed to maximise volume and grade recoveries. Each method was examined 3 times, varying the maximum number of edged pieces (from each flitch) from 1 to 3 (simulating 2 to 4 saws). An increase in total volume of approximately 28% was obtained when the maximum number of edged pieces was increased from 1 to 2, and a further 4% increase in volume when increased from 2 to 3.

edging / docking / volume optimisation / grade optimisation

Résumé — **Effets des méthodes de délignage et de rognage sur les rendements en volume et en classe de qualité dans la production de plots obtenus par simulation.** *L'article décrit les procédures de délignage qui ont été adaptées pour leur emploi dans AUTOSAW, un système de simulation de sciage de grumes élaguées développé à l'Institut de recherches forestières de Nouvelle-Zélande. Des simulations automatisées de sciage ont été réalisées sur un échantillon de 20 grumes élaguées en utilisant un plan de débit standard. Ces simulations ont produit un total de 483 plots dont 221 pour lesquels des opérations de délignage et de rognage ont été requises. Les méthodes ont été développées afin de maximiser les rendements en volume et en classe de qualité. Chaque méthode a été examinée 3 fois en faisant varier de 1 à 3 le nombre maximum de pièces délignées dans chaque plot (simulation de 2 à 4 scies de reprise). Une augmentation d'environ 28% a été obtenue pour le volume total quand le nombre maximum de pièces délignées passait de 1 à 2 ; quand ce nombre maximum passait de 2 à 3, une augmentation supplémentaire de 4% a été obtenue.*

délignage / rognage / optimisation du volume / optimisation du classement

INTRODUCTION

In a sawmill, primary breakdown involves cutting logs into flitches at the main saw. These flitches are in turn cut horizontally into edged pieces after which the rough end sections are cut off, docked, to complete the secondary breakdown process.

Cutting flitches into edged pieces involves super-imposing edger sawlines on a flitch such that the target widths can be cut. With each edge cut an amount equal to the edger sawkerf is lost in the form of sawdust. All edged pieces must be feasible with respect to a minimum grading length criteria and to a maximum wane tolerance level. To achieve this, docking sawlines are super-imposed on the edged piece. A solution is sought in which the total recovery is maximised. For the purposes of this paper recovery is measured in terms of nominal volume and grade. As the thickness of each edged piece is assumed to be constant the problem can be stated as follows:

$$\text{Maximise} \sum_{i=1}^{N} \sum_{j=0}^{M} \sum_{k=0}^{D-1} X_{ij} \bullet WN_i \bullet g_{ijk} \bullet a_{jk} \bullet (Z_{j,k+1} - Z_{j,k})$$

$$\text{subject to} \sum_{i=1}^{N} \sum_{j=0}^{M} X_{ij} \leq M+1$$

$$\sum_{i=1}^{N} \sum_{j=0}^{M} X_{ij} \bullet (WA_i + K) \leq F_{ymax} - p_0$$

$$F_{ymin} \leq p_0 \leq F_{ymax} - WA_1 - K$$

$$p_j = p_{j-1} + \sum_{i=1}^{N} X_{ij} \bullet WA_i + K \quad j = 1..M$$

$WA_i \geq WN_i$ $\quad i = 1...N$

$X_{ij} = 0$ or 1 $\quad i = 1...N, j=0...M$

$Z_{j,o} = F_{zmin}$ $\quad j \in 0...M$

$Z_{j,D} = F_{zmax}$ $\quad j \in 0...M$

$a_{j,k} = 1,\ Z_{j,k+1} - Z_{j,k} \geq l_{min}$

$\quad Z_{j,k},\ Z_{j,k+1} \in U_{j,k}(z,y) \vee L_{j,k}(z,y)$

$\quad ymax_{j,k} - p_j \leq \delta$

$\quad ymax_{j,k} = \max \{L_{jk}(z,y)\}$

$\quad p_j - ymin_{j,k} + \sum X_{ij} \bullet WA_i \leq \delta$

$\quad ymin_{j,k} = \min \{U_{jk}(z,y)\}$

$\quad i \in 1...N\ j \in 0...M\ k \in 0...D-1$

0, otherwise

$g_{ijk} \geq 0$

where:

N: number of target widths;

M: number of edged pieces which may be produced from each flitch (thus there may be $M+1$ edger sawlines);

D: maximum number of docked pieces per flitch $D = 1 + (F_{zmax} - F_{zmin})\ DIV l_{min}$ (see explanation of terms below);

K: width of the edger sawkerf;

WA_i: actual dimension of target width i;

WN_i: nominal dimension of target width i;

P_j: position of edger sawline j;

x_{ij}: equals 1 if a piece of width WA_i is cut such that the lower edge of the piece is at edger sawline position p_j, 0 otherwise;

g_{ijk}: coefficient which reflects grade of piece with actual width WA_i and length $z_{j,k+1} - z_{j,k}$ cut from position p_j of edger sawline when problem is to maximise grade recoveries. For maximisation of volume recoveries $g_{ijk} = 1$ for all i,j,k;

F_{ymin}, F_{ymax}: minimum and maximum y coordinates of flitch;

F_{zmax}, F_{zmin}: minimum and maximum z coordinates of flitch;

l_{min}: minimum grading length;

$z_{j,k}$: z coordinate of k_{th} docking sawline and j_{th}: edger sawline;

δ: maximum wane tolerance level;

a_{jk}: equals 1 if the board is bounded by jth edger sawline and kth docking sawline (see explanation below) is feasible with respect to the minimum grading length criteria and maximum wane tolerance level, and is 0 otherwise;

$U_{jk}(z,y), L_{jk}(z,y)$: upper and lower coordinates respectively of board face bounded by jth edger sawline and kth docking sawline;

$y\max_{j,k}$: maximum y coordinate of $L_{j,k}(z,y)$;
$y\min_{j,k}$: minimum y coordinate of $U_{j,k}(z,y)$.

Recall that the edger and docking sawlines are super-imposed on a flitch. Thus the jth edger sawline and kth docking sawlines define a rectangle with coordinates: $(z_{j,k}, p_j)$ $(z_{j,k+1}, p_j)$ $(z_{j,k+1}, p_{j+1} - K)$ $(z_{j,k}, p_{j+1} - K)$. Thus the shape of the board cut is a polygon which lies on or within this rectangle. Consequently for every z_s: $z_{j,k} < z_s < z_{j,k+1}$ there are exactly 2 y coordinates y_s, y_t corresponding to the upper and lower edges of the board. Let $U_{jk}(z,y)$ consist of those coordinates (z_s,y_s) where $y_s \geq y_t$, $z_s = z_t$ which define the upper edge of the board and let $L_{jk}(z,y)$ consist of the coordinates z_t,y_t where $y_t < y_s$, $z_s = z_t$ which define the lower edge of the board. Now the worst wane on the upper edge of the board (*ie* worst deviation from $p_{j+1} - K$) is due to the minimum value of y in $U_{jk}(z,y)$ *ie* $y\min_{jk}$ and the worst wane on the lower edge of the board is due to the maximum value of y in $L_{jk}(z,y)$, *ie* $y\max_{j,k}$.

Edging and docking operations have been identified as potential sources of recovery improvement in sawmills (Hamlin, 1983). Improved recoveries not only contribute to an increase in value but also to better utilisation of wood and hence to improved utilisation of a valuable resource.

Although edger 'optimisers' are commercially available their high cost (between $750 000 and $1.5 million) is a major drawback. These 'optimisers' can achieve 85–95% of the theoretical maximum recoverable amount of timber for each flitch whilst the average edger operator achieves about 65–75% (Doyle, 1989). Documentation of the procedures used by commercial edgers does not appear to be readily available.

Regalado *et al* (1992) describe a procedure that maximises timber value from a given flitch. In the following extract, the term 'trimming' is equivalent to 'docking'; and 'cutting-line combinations' refers to the combinations of edging and docking lines. "*... The method was to: 1) iteratively generate combinations of edging and trimming lines; 2) evaluate grade and volume yielded by each edging and trimming line combination; and 3) select the combination of edging and trimming lines that maximised lumber value.*"

The procedure was restricted to producing one edged piece or "*... ripping to produce 2 lumber pieces was allowed in cases where these operations were thought to possibly improve lumber value beyond that obtainable from the iterative variation of cutting lines. Cutting line combinations were generated by varying the coordinates of each edging and trimming line between predetermined limits.*" These limits, by the authors' own admission, involved some degree of subjectivity.

Lewis (1985) uses a different procedure by which a reference line is established and the flitches edged parallel to this line. Two edging methods are used. The first method was full-length edging which "*... simulates cutting the widest full-length piece of lumber possible as an edger operator might do. If a model cannot find a full-length piece, it re-establishes the reference line, and will try to fit a 2-foot shorter piece somewhere in the flitch. This process continues until a piece is found. Where possible, the model will remanufacture the remainder of the flitch into a piece of lumber.*" The second method, trim-back edging, "*... simulates an automated optimizing edger where only combinations based on the widest piece are cut.*" This method also produces 1 or 2 edged pieces per flitch.

The edging procedures presented produce 1, 2, or 3 edged pieces per flitch. A description of these procedures follows.

MATERIALS AND METHODS

Two heuristic procedures for the edging/docking of flitches were examined. The first is a 'brute-force' iterative procedure which obtains optimal (or near optimal) volume (or grade) recoveries and, as such, provides a benchmark for comparison purposes. The second is a heuristic procedure that utilises the known geometry of each flitch to obtain a 'good' solution quickly. The objective of both procedures is to edge and dock each flitch so as to maximise volume (or grade) recovery.

Both procedures, under both objective functions, were implemented in the pruned log sawing simulator AUTOSAW (Todoroki, 1990), (compiled with Turbo Pascal and running on a 33 MHz 80486 processor) giving 4 different edging methods. A sample of 20 logs were then processed in the simulator using a standardised sawpattern (Park, 1989). This gave a total of 483 flitches of which 221 flitches required edging/docking operations to be applied (182 flitches were 'cant' flitches, rectangular flitches obtained from the inner part of the log, and 80 flitches were 'wing' flitches, the first cut on each face of the log).

Each method was tested 3 times, varying the maximum number of edged pieces, M, from 1 to 3 (simulating edgers with 2–4 saws and/or allowing for a splitting saw option).

The following values were used for all tests:

δ	10.0 mm
l_{min}	1.8 m
N	8
WA	{50, 75, 100, 125, 150, 200, 225, 250}
WN	{50, 75, 100, 125, 150, 200, 225, 250}
K	5.0 mm

The coefficient for the grade weights g_{ij} is 1.0 when the problem is to maximise volume and 1.0, 0.833, 0.667, 0.500, 0.333, 0.167 for grades *c, x, s, f, k, p,* respectively, when the problem is that of maximising grade recovery. The grades are defined in *Appendix 1* and are based on New Zealand timber grading rules (Sanz, 1987).

Brute force iterative procedure

A brute force procedure was developed in order to obtain optimal (or near optimal) recoveries from each of the flitches. This procedure involved the following steps:

1) recursively generate all feasible combinations of the given widths;

2) permute each of the generated feasible combinations;

3) for each permutation, super-impose a reference line on the flitch at regular intervals, and determine the recovery associated with each interval;

4) select the permutation which allows greatest recovery.

A feasible combination is one for which the total width of that combination (including allowances for edger sawkerfs) is no greater than the widest bounds of the flitch.

Each feasible combination is permuted using the HeapPermute algorithm due to Heap (1963) and outlined in *Appendix 2*. It is necessary to permute the combinations since different cuts would results. An example is given below.

Example

Let $M = 3$, $N = 2$ with $WA_1 = 50$ mm, $WA_2 = 75$ mm and the flitch width = 200 mm. The following combinations are then generated, where the first number is the coefficient of the first width (50 mm) and the second width (75 mm):

(3,2) (3,1) (3,0) (2,2) (2,1) (2,0)
(1,2) (1,1) (1,0) (0,2) (0,1) (0,0)

Since $M = 3$, then combinations (3,2) (3,1) (2,2) are infeasible. (0,0) is also infeasible since there must be at least one cut. In addition, (1,2) is also infeasible as this would exceed the flitch width (since edger sawkerfs must also be included).

The combination (2,1) represents two 50 mm cuts and one 75 mm cut. Since the order of cutting can make a considerable difference, the permutations of this combination are also required, *ie* (50, 50, 75), (50, 75, 50), and (75, 50, 50).

The interval chosen for the reference line increments was 0.5 mm, starting from the lowermost edge of the flitch. Although, theoretically, this does not actually guarantee that the optimal solution will be found, it is beyond the accuracy of any mill equipment currently available, and in addition, all measurements were made to the nearest millimetre so for all practical purposes the solution generated can be treated as being optimal.

Geometric procedure

A different approach, similar to that of Lewis (1985), was developed with flitches being edged parallel to reference lines. These are positioned:

1) at the lower wane edge of the flitch with edging occurring above this line (fig 1a);

2) at the upper wane edge of the flitch with edging occurring below this line (fig 1b);

3) mid-way between the 2 wane edges of the piece with edging being centred around this line.

For the case of volume maximisation, the combination of pieces that gives the largest total nominal volume is selected. For grade maximisation, an initial solution is obtained using the above method with weighted volumes. In addition, if the flitch, or some part of the flitch, lies within the defect core then further reference lines are established. These lines are determined by the extent of the defects and are positioned:

4) at the bottom of the lowermost defect with edging occurring above this line (fig 1c);

5) at the top of the uppermost defect with edging occurring below this line (fig 1d);

6) mid-way between the uppermost and lowermost defect extremes with edging centred around this line.

Of the 221 flitches, 52 contained defects. As the remaining 169 flitches are defect-free edging for grade recovery produces the same result as the edging for volume recovery. Thus only the grade recoveries of these 52 flitches may differ, so grade comparisons are restricted to these flitches.

RESULTS

Table I shows the total processing times (rounded to the nearest minute) for the 20 logs, for each edging method.

The volumes of the 221 flitches that had been edged/docked using the brute force and heuristic procedures were calculated for each of $M = 1, 2, 3$. The total volumes attributed to these flitches for each of the logs were then calculated and are shown in table II. An increase in volume of approximately 28% ($\mu = 28$, $\sigma = 13$) was obtained when the maximum number of edged pieces was increased from 1 to 2, and a further 4% increase in volume ($\mu = 4$, $\sigma = 2$) when increased from 2 to 3.

The percentage volume (geometric heuristic/brute force)% was calculated for each of the 221 flitches and the result rounded to the nearest integer. The number of occurrences at each percentage are shown in table III. Table IV summarizes these results, showing the number and percentage of fliches which obtained at least 95 and 90%, respectively, of the 'optimal' volume for each of $M = 1$, 2 and 3.

Figure 2 shows a comparison of the grade recoveries for the 52 flitches containing defects, for the heuristic (H), and brute force (BG) procedures. The grade recoveries of the same 52 flitches obtained when maximising volume using the brute force procedure (BV) are also given.

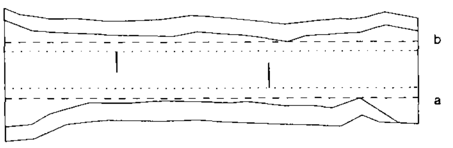

Fig 1. Reference lines for a geometric heuristic procedure.

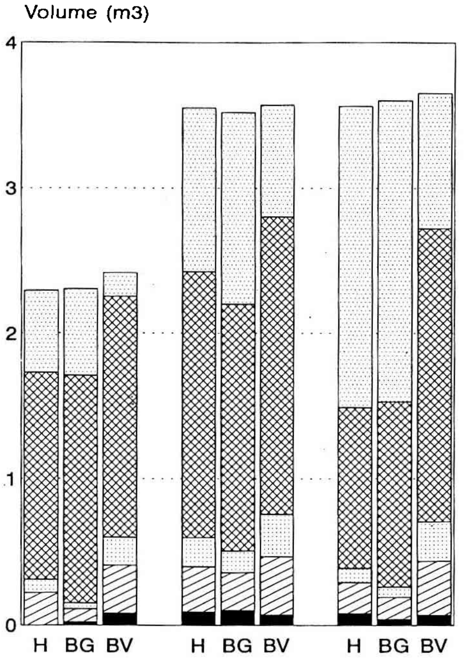

Fig 2. Grade distributions. M = 1–3 edged pieces per flitch. ▤ c; ▩ x; ▤ s; ▨ f; ■ k.

Table I. Times for processing 20 logs (rounded to the nearest minute).

Edging method	*M**		
	1	*2*	*3*
Edging for volume			
Brute force	15	85	364
Geometric	1	1	1
Edging for grade			
Brute force	44	320	1 638
Geometric	2	3	3

**M*: No of edged pieces per flitch.

DISCUSSION

The computational results demonstrate that the geometric heuristic procedure obtained good results when compared with the brute force procedures for both volume and grade maximisation problems.

The geometric heuristic procedures provide rapid processing times and as such would be acceptable to existing sawmills, whereas the brute force procedures were very slow, and would be impractical for real-time situations. The 28% increase in volume observed when *M* was increased from 1 to 2 seems to indicate that an edger with only 2 saws (*ie* *M* = 1) produces much

Table II. Total flitch volumes by log (m^3).

Log	*M = 1*		*M = 2*		*M = 3*	
	GH	*BF*	*GH*	*BF*	*GH*	*BF*
1	0.483	0.488	0.644	0.655	0.666	0.677
2	0.567	0.575	0.911	0.914	0.941	0.947
3	0.465	0.467	0.724	0.726	0.765	0.778
4	0.363	0.376	0.435	0.441	0.450	0.460
5	0.474	0.477	0.660	0.670	0.681	0.687
6	0.277	0.277	0.375	0.382	0.377	0.387
7	0.486	0.503	0.698	0.713	0.712	0.733
8	0.268	0.270	0.351	0.353	0.356	0.370
9	0.315	0.318	0.370	0.372	0.380	0.383
10	0.469	0.474	0.621	0.633	0.653	0.662
11	0.278	0.285	0.339	0.342	0.345	0.352
12	0.320	0.327	0.352	0.357	0.359	0.367
13	0.236	0.238	0.292	0.292	0.295	0.307
14	0.442	0.456	0.548	0.559	0.576	0.589
15	0.361	0.377	0.428	0.438	0.443	0.449
16	0.350	0.355	0.479	0.484	0.507	0.517
17	0.351	0.362	0.412	0.416	0.421	0.430
18	0.259	0.267	0.316	0.325	0.318	0.327
19	0.352	0.357	0.408	0.412	0.415	0.419
20	0.449	0.460	0.549	0.553	0.557	0.566
Total	7.565	7.709	9.912	10.037	10.217	10.407

M = number of edged pieces per flitch; GH = geometric heuristic (maximising volume); BF = brute force procedure (maximising volume).

Table III. Heuristic performance.

Percentage volume	No of observations		
	M = *1*	M = *2*	M = *3*
103	1	–	–
102	1	1	1
101	–	–	–
100	147	130	92
99	11	17	29
98	8	16	26
97	7	11	11
96	5	10	13
95	–	9	14
94	1	12	16
93	5	2	5
92	2	4	7
91	2	4	2
90	4	1	2
89	2	1	1
88	4	–	1
87	–	–	–
86	4	1	–
85	–	–	–
84	4	–	–
83	2	1	–
82	–	–	–
81	1	–	–
80	–	–	–
79	2	–	–
78	2	1	1
77	–	–	–
76	1	–	–
75	2	–	–
74	1	–	–
73	–	–	–
72	–	–	–
71	–	–	–
70	2	–	–

reduced volume recoveries. The recoveries were notably poor for larger logs (see *Appendix 3* for some log characteristics) and can be attributed to the fact that the largest 'target' size sawn was 250 mm. This represents a mismatch between the logs and the selected target sizes resulting in much wood being wasted. However, in practice, further processing could recover some of this wastage (which is equivalent to incrementing *M*).

Table IV. Number (and percentage) flitches obtaining percentage optimal volume.

	Percentage optimal volume	
	95%	*90%*
M = 1	180 (81)	194 (88)
M = 2	194 (88)	217 (98)
M = 3	186 (84)	218 (99)

As can be seen in table III, the geometric heuristic procedure obtained a better result than the brute force heuristic on 2 occasions for case M = 1 and once for each of M = 2, 3 (these were actually due to the same flitch, and with only one edged piece being taken in each, since a solution for *M* = 1 is also a solution for *M* = 2, and so on). This shows that the even with a step increment of 0.5 mm, the optimal solution is not guaranteed.

Figure 2 compared the grade recoveries of the 52 flitches containing defects. As was to be expected, better grade distributions were obtained for both the geometric heuristic procedures and the brute force procedure when the objective was to maximise grade recoveries. However, the comparatively poor results obtained from the brute force edging procedure when the objective was to optimise volume recoveries should be noted with some concern. For flitches with defects this procedure is inappropriate. However, very few 'optimising' edger machines that are currently available have grade input capabilities hence many mills will be under-achieving in terms of recovered timber grades (and hence the value of the resultant timber will also be reduced).

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APPENDIX 1

AUTOSAW grading rules: 'c': *clear* – there are no defects on either of the flitch faces; 'x': *clear one face* – one of the 2 faces is defect free; 's': *shop* – the total length of clear cutting lengths exceeds 2 000 mm, and covers at least 70% of the flitch length. The lengths of clear cuttings must be at least 1 000 mm long, with each length truncated to the nearest 100 mm; 'f': *factory* – the total length of clear cutting lengths exceeds 1 800 mm, and covers at least 50% of the flitch length. The lengths of clear cuttings must be at least 600 mm long, with each length truncated to the nearest 300 mm; 'p': *pith* – the pith lies on, or within, the flitch. Otherwise the grade is: 'k': *knotty with pith.*

APPENDIX 2

```
Procedure HeapPermute (n: Integer);
Var c: Integer; {c, an index}
Begin
  c: = 1;
  If n > 2 Then
    HeapPermute (n-1)
  Else
    ProcessPermutation;
  While c < n Do
    Begin
    If Odd (n) Then
      Swap (1,n)
    Else
      Swap (c,n);
    c: = c + 1;
    If n > 2 Then
      HeapPermute (n-1)
    Else
      ProcessPermutation
    End
End {HeapPermute}
```

APPENDIX 3

Sample log characteristics.

Log No	*Length (m)*	*SED (mm)*	*LED (mm)*
1	6.1	567	660
2	5.2	652	730
3	4.2	666	818
4	6.0	459	610
5	4.8	579	706
6	4.0	565	650
7	5.4	543	700
8	4.2	484	575
9	5.1	460	559
10	5.2	545	688
11	5.4	460	657
12	5.7	404	528
13	4.2	449	541
14	5.7	560	680
15	5.1	501	645
16	4.2	634	807
17	4.8	465	564
18	5.2	466	523
19	6.0	398	484
20	6.2	491	602

SED = small-end diameter; LED = large-end diameter.