A METHOD FOR ASSESSMENT OF RECOVERABLE VOLUME BY LOG TYPES

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ABSTRACT

This paper describes a method for assessing the recoverable volume by log types of a single species stand of trees shortly before harvesting. The method takes into account the influences on yield of stem quality and malformation, and of log specifications and preferences. Trees are cruised for quality and malformation. No attempt is made to divide trees into logs in the field. During computer analysis of the inventory data, lists of log specifications and values control a dynamic programming optimisation process which estimates the potential yield from each stem. A test of the method at ten clearfelling sites indicated that good results were attainable, the overall error in recovered volume being 3.7 percent. An operational system based on the method is now being used by the N.Z. Forest Service.

INTRODUCTION

Forest managers responsible for marketing, work study and logging planning require detailed information on the potential yield and log size distribution likely to result from felling a stand of trees. Information is required on the potential of the stand to yield differing types and qualities of logs as a result of different ways of cross-cutting the stem, on average piece sizes for extraction, and on the number, size and volume of the individual log types. This paper describes a method that has recently been developed by the New Zealand Forest Service for the assessment of the recoverable volume by log types of a single species stand shortly before harvesting.

The existing inventory procedure used by the N.Z.F.S. (Lees, 1967) provides broad-based estimates of standing volume which are modified by experience factors to estimate recovered volume. It is unable to provide detailed figures by product breakdown and is inadequate when factors are unavailable or when it is necessary to differentiate the merchantability of individual stands for diverse markets. It is essential that detailed inventory data by product type, specific to locatable areas at the stand level ("in place inventory"), be available in order for modern management methods to realise the maximum contribution from the timber resource (Campbell, 1974).

The product yield of a stand is influenced both by the characteristics of the stand and by the method of cross-cutting the stems.

Some of the older exotic stands in New Zealand contain considerable quantities of high quality stems. However, partly because of the lack of tending, defect and malformation are often present in the final crop. Forking, where the main leader divides into two or more subsidiary stems, is prevalent. This variation in quality and malformation is a major influence on log production in the older stands. The problem will continue, for although many of the newer stands have been pruned and tended to improve the quality of the butt logs, there are still large areas which will not receive further treatment after an initial slasher thinning. If anything, in future there may be more variability in quality than in the past.

The log production of a stand is also affected by the types of logs being produced. There is a wide range of log qualities and sizes being cut in New Zealand, but even when qualities and dimensions remain fixed, changes in the order of preference of logs can lead to merchantable material being wasted in order to increase the volume of preferred log types, or high grade material being downgraded to bring lower grade logs up to a required length.

In this assessment method the authors have taken the approach of selecting a sample of trees and recording their stem size, quality and malformation in so far as these are likely to influence yield, and then separately analysing this information in relation to a given set of log requirements to assess available yield. The information can be reanalysed with different sets of log requirements without revisiting the stand.

The field procedure was developed from an existing cruising method developed by P. Crequer (unpubl.). Crequer's method for estimating stem size, defect and malformation has been found to give good results at the stand level (Elliott, 1970; Mackintosh and Park, 1971; unpubl. reports).

The field data are analysed by evaluating volume and taper for each cruised tree then simulating the effects of felling, stem breakage and cross-cutting according to a "cutting strategy", which is a list of log types described by size, allowable quality and value. The total value of logs from each stem is maximised using an optimisation routine, the relative values of log types controlling the extent to which material is downgraded or wasted to improve the total return. Individual tree results are accumulated to provide estimates of plot, stratum and population means.

The use of optimisation and the separation of the description of log types from the field cruise distinguish this method from other inventory systems, for example STX and 3P (Grosenbaugh, 1974; Gyde Lund, 1975); FINSYS (Wilson and Peters, 1967); or the Purdue system (Moser, 1972).

METHODS

Field Procedure

Each sample tree is measured for d.b.h. Enough normal and malformed trees are measured to derive a height/diameter regression, which is used to estimate the heights of the remaining trees. The entire stem is "cruised", or partitioned into variable length intervals, each of which can be considered to be of uniform quality. Quality, judged by the presence or absence of defects, is the sole criterion used in this cruising — no attempt is made to divide the tree into logs, estimate the height to merchantable limits, or alter the classification of an interval on the basis of stem size or interval length. It is possible and often useful to classify an entire stem as being of a given quality, even though logs of that quality could be cut only from the butt because of size constraints.

One-letter alphabetic codes ("feature codes") are used to designate stem quality classes when recording the results of cruising. The quality classes and their codes are defined prior to the inventory to suit the objectives of the particular assessment. The only invariant feature codes are used to define the structural features of a stem that always affect volume or require special cutting. These "structural codes" are F (fork), S (large branch), R (diameter reduction), X (dead wood or dead tree) and T (tip of unusually short leader in a multiple leader tree).

Forks, large branches and diameter reductions all require estimation of diameters at 1.4 metres above the top of the defect. For a diameter reduction, this is the diameter of the main stem above the reduction; for a branch, the diameter above its junction with the main stem; and for forks, the diameter of each new stem 1.4 metres above its base. The structural code used to describe the affected region indicates whether the main stem must be cut (fork), left uncut (diameter reduction) or separated from a large branch by a chamfer cut (branch). Individual limbs are assessed for quality and malformation in the same way as a whole tree. Each limb is assumed to reach the same total height above ground as the rest of the tree unless a different height is recorded for it.

Observations for each tree are recorded directly on a computer input form which has across the page columns for "features". A feature is an interval of one quality or structural class, described by the relevant feature code, height above ground, and length. Successive intervals up the stem are recorded from left to right across the page. Upper stem diameters are recorded immediately to the right of the features above which they occur; the second and any other diameters relating to a fork are recorded on separate lines immediately below the first, with all columns on the same line and to the right of a diameter available for description of the features of the limb. Very complex combinations of structure and quality breaks can be represented if necessary. The formal representation of the tree has a diagrammatic appearance which is easy to understand and check. An illustration of normal, variable quality and malformed trees is given in Fig. 1.

Calculation of Volume and Taper

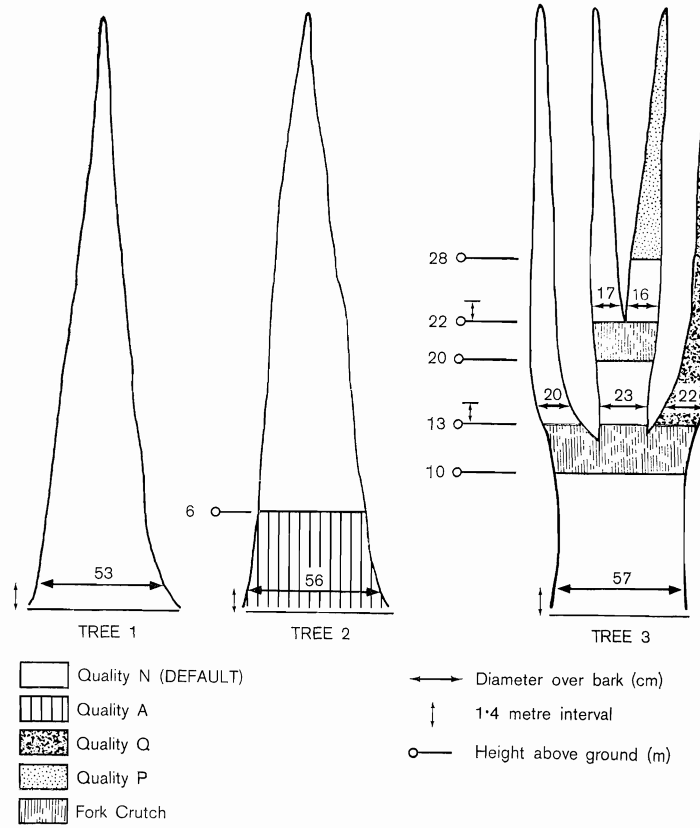
For normal single leader trees a suitable general function is used to derive volume inside bark from breast height diameter over bark and total height. A limb or the stem above a diameter reduction is treated as an ordinary tree with its d.b.h. equal to the assessed diameter, its height being obtained by subtracting its starting height from the total height of the tree.

General taper functions are used to derive diameter inside bark and volume cumulative from the top of the tree, to any point on the stem. These functions use total height, d.b.h., total volume inside bark and distance from the tip as parameters, and are compatible with the volume equation in the sense that the total tree volume is always equal to the sum of its sectional volumes, regardless of the location of the sections. Derivation of equations of this type for *P. radiata* is described by Goulding and Murray (1976).

Simulation of Felling and Breakage

In calculating the volume of stumps, each live tree is assumed to be cut at a height above ground that is held constant for a given analysis.

A breakage simulator randomly selects trees to incur breakage in such a way that



PLOT NUMBER: 1 | AREA (ha) OR B.A.F.: 0·010 | SLOPE: 0° | ASSESSMENT CODE NAME: DEMO0000

P 1

COMMENTS

P 2 CRUISING OF NORMAL, VARIABLE QUALITY AND MALFORMED TREES

CONTINUATION ONLY
PAGE 1 OF 1
PLOT 1

PLOT MEASUREMENT FORM

				FEATURE				FEATURE				FEATURE				FEATURE			
	TREE NO.	DBH. OB cm	TOTAL HEIGHT m	CODE	HEIGHT m	LENGTH m	DIAM OB cm	CODE	HEIGHT m	LENGTH m	DIAM OB cm	CODE	HEIGHT m	LENGTH m	DIAM OB cm	CODE	HEIGHT m	LENGTH m	DIAM OB cm
1 2	3 4 5	6 7 8 9	10 11 12 13	14	15 16	17 18	19 20 21	22	23 24	25 26	27 28 29	30	31 32	33 34	35 36 37	38	39 40	41 42	43 44 45
P 9	1	53.0																	
P 9																			
P 9	2	56.0		A	0	6													
P 9																			
P 9	3	57.0		F	10	3	20												
P 9							23	F	20	2	17								
P 9											16	P	28						
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FIG. 1—Methods used to record stem size, quality and malformation during cruising.

all trees have the same probability of breaking. For the selected trees an expected relative break point height is derived from a general function which has average ground slope and total height as parameters. Derivation of functions of this type for several species is discussed by Manley (1977, unpubl. rep.). A random component normally distributed about a mean of zero is added to this relative height and the total multiplied by tree height to give a final break point height. All leaders of a multiple leader tree are broken at the same height. All material above the break point is treated as waste due to shattering.

Simulation of Cross-Cutting

The section of stem between stump and break point is initially "trimmed" by cross-cutting across the top of any interval described by the structural code "F" (fork), and by separating any recorded branches from the main stem. This leaves one or more basic pieces to be cut into product logs. (A double-leadered tree will generate three pieces, a normal tree one, and an otherwise normal tree with one large branch recorded will generate two.)

In many cases there will be an infinite number of ways in which a piece may be cut into logs, but in practice the cross-cutter on the skids will give preference to certain log types when a choice exists, even to the point of sacrificing a possible log to produce a preferred one elsewhere. In principle this cross-cutting process may be viewed as the division of a piece into logs in such a way as to maximise some measure of value over the whole piece, subject to constraints on log size and quality. We have assumed that the value of the piece is the sum of the values of the individual logs, reduced by a fixed amount for each saw cut required; and that for logs of a given type, the value is proportional to volume inside bark. The values per unit volume for individual log types are defined by the user to meet the objectives of the assessment. The relative values determine the extent to which material may be downgraded into less valuable log types or wasted in order to cut more valuable logs elsewhere. Where different lengths can be cut for one log type the inclusion of a cost of sawcuts encourages the cutting of longer logs. If real dollar values are used in the analysis then the predicted outturn will be an estimate of the yield that could be realised under ideal management conditions.

The maximisation technique used is a dynamic programming method originally conceived for use in automated sawmilling (Pnevmaticos and Mann, 1972). The piece is divided into fixed length intervals for each of which the volume, end diameters and quality are estimated by the taper equations. The technique works by proceeding from the trivial solution for one interval to a solution for the whole piece in an inductive fashion. Essentially the principle is that given the optimal result for each of the preceding n-1 intervals. the sum of the value at the nth interval after cutting a log of length m intervals plus the value of the optimal result for the first n-m intervals, can be calculated for all feasible log lengths. The log type and value of m that give the maximum value are retained as the optimal combination for the nth interval.

A solution produced in this way is not necessarily unique; in particular if a long log and a short one of the same type are both to be cut from one piece, they can often be interchanged without altering the value of the piece. We assume that in such cases the longer logs should be cut closer to the butt.

TESTING

Although each component of the assessment method had been tested individually, there was considerable doubt as to whether the detail required in the predictions of volumes and numbers would be adequate or not. A pilot program was first constructed and a testing procedure carried out on this before the current system was implemented.

The obvious test would have been to assess several cutting units prior to logging and to predict the total recovered volume comparing the predictions with actual volumes as measured by the weighbridge. This poses several difficulties, not least being the uncertain accuracy of the volume totals purported to come from a given area as measured by the weighbridge, the length of time between the assessment and the completion of felling, and lack of necessary detail of the product breakdown. Instead it was decided to visit ten felling gangs, assess 25 trees at each and follow the trees through the felling and cross-cutting process. This would remove any variability due to sampling and ensure that the actual results would be accurately measured.

Three Forest Service (Waipa Sawmill) gangs, three independent contractors and four gangs from a large private company (Kaingaroa Logging Company) were selected who were clearfelling mature old crop *P. radiata* at Kaingaroa. The stands were all on flat tractor country, but varied in quality from high to low with an average tree size ranging from 6 to 1.7 m^3/tree. In the low quality stands malformation was prevalent.

The selection of the felling face was made at the convenience of the logging gang. From the mensurational view point this was at random. At each face, 25 trees were selected for ease of felling and to cover the range of trees at the face. The trees were numbered, cruised, measured for total height and felled. The stems were extracted and cross-cut by the gang during their normal work; whilst it could be said that these stems were readily identifiable and could have been treated as special cases, it was felt that they were treated no differently from the remainder of the stand. The actual yield of logs by type, the amount of waste left in the bush below a 10-cm top, and waste on the skids were all accurately measured. To the bush waste was added 1% of the total standing volume to account for unmeasured material of less than 10 cm diameter. The actual cutting pattern used by each gang was used in the analysis to estimate the recoverable volume by log type for the cruise data.

A wide variety of cutting patterns was employed. They included cutting logs for peelers (one gang), for railways sleepers (two gangs), a variety of lengths of long sawlogs (10, 11, 12 m fixed, 10-11 m random lengths), short sawlogs, and pulp (fixed length, random 3.5-6.1 m shorts and long logs). The field crew had difficulty in recognising the quality of the railway sleeper and peeler material, partially because they were newly trained and partially because the specifications were loosely written. For example, peelers were described as "cylindrical"; the description has now been corrected and replaced by "no more than five centimetres difference betwen two diameters at right angles". The log types have been amalgamated into broader classes of products (peelers and sleepers are included with long sawlogs), and the results averaged over the ten gangs are given in Table 1. Figures 2 and 3 depict the results for each stand and vividly illustrate the wide differences in quality and mean tree size.

With one exception, the predictions of both volume and numbers of logs are accurate. The method was unable to predict accurately the division into long and short pulp, with errors of 32 and 33% (though these errors were only 4% of the total standing

TABLE 1—Results of the tests of assessment made at 10 felling gangs

	Mean Volume m³/felling gang (25 trees) Actual	Error†	Percent Error	Correlation Coefficient
Total Standing Volume	97.5	1.9	1.9	
Recovered Volume	83.7	3.1	3.7	0.94
Bush Waste	6.8	—0.3	—4.4	0.49
Skid Waste	4.2	—0.5	—11.9	0.71
Stumps	2.8	—0.4	—14.3	
Sawlogs and Better	64.8	5.4	8.3	0.95
Pulpwood	18.9	—2.3	—12.2	0.66
Long Sawlogs (10-12 m) and better	54.4	5.9	10.8	0.89
Short Sawlogs (3.6-6.1 m)‡	17.3	—0.8	—4.6	0.75
Long Pulp‡	9.9	3.2	32.3	0.76
Short Pulp (3.6-6.1 m)	12.9	—4.2*	—32.6*	0.70

	Mean Nos. of logs/felling gang (25 trees) Actual	Error†	Percent Error
Recovered logs	102.7	2.4	2.3
Sawlogs and Better	55.0	2.9	5.3
Pulpwood	47.7	—5.3	—11.1
Long Sawlogs and Better	36.9	0.7	1.9
Short Sawlogs‡	30.1	—3.7	—12.2
Long Pulp‡	21.3	1.7	7.8
Short Pulp	34.9	—5.7	—16.3

† Error = Predicted — Actual

‡ Six gangs only

* Difference significant from 0 at 5%

volume). The errors cancelled each other, resulting in a 12% underestimate of the total pulp volume recovered (representing an error of 2% of the total volume). The error in the recovered volume on the skids was only 3.7%. Surprisingly low were the average errors in the estimates of the amount of waste left in the bush and on the skids, as the model for breakage and wastage is relatively crude.

Paired t tests were performed on mean differences between actual and predicted values, and the correlation coefficients tested for significance for the various log types cut by each gang. Only the error in the prediction of short pulp was significantly different from zero, though the correlation coefficient was significant, indicating that the assessment tended to overpredict the amount of long pulp at the expense of short pulp but was able to differentiate between those stands yielding greater or lesser amounts of pulp. The correlation coefficient for bush waste was not significant; this could be

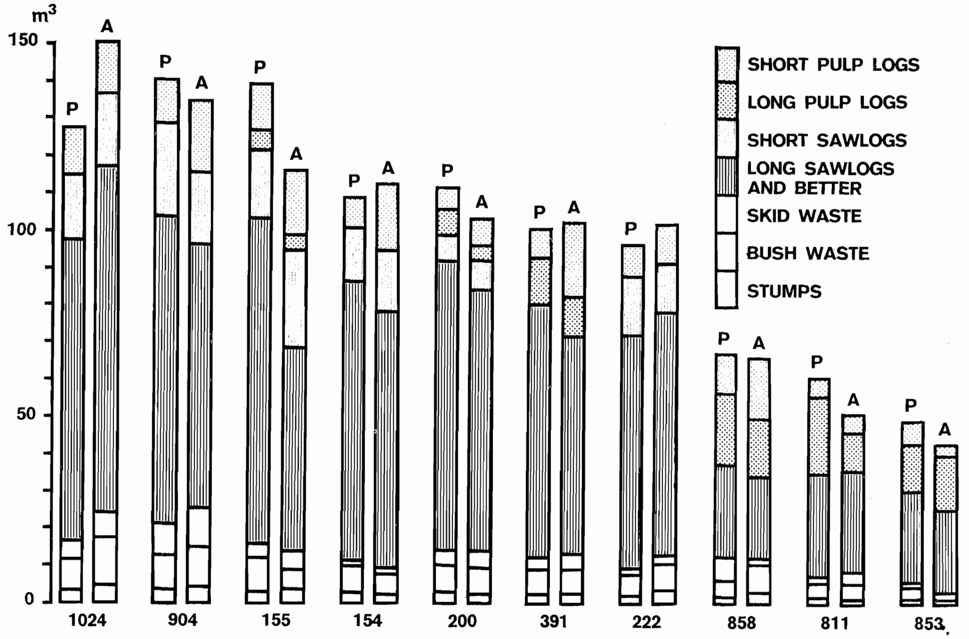


FIG. 2—Actual vs. predicted volume
Total of 25 trees each compartment.
10 compartments Kaingaroa State Forest

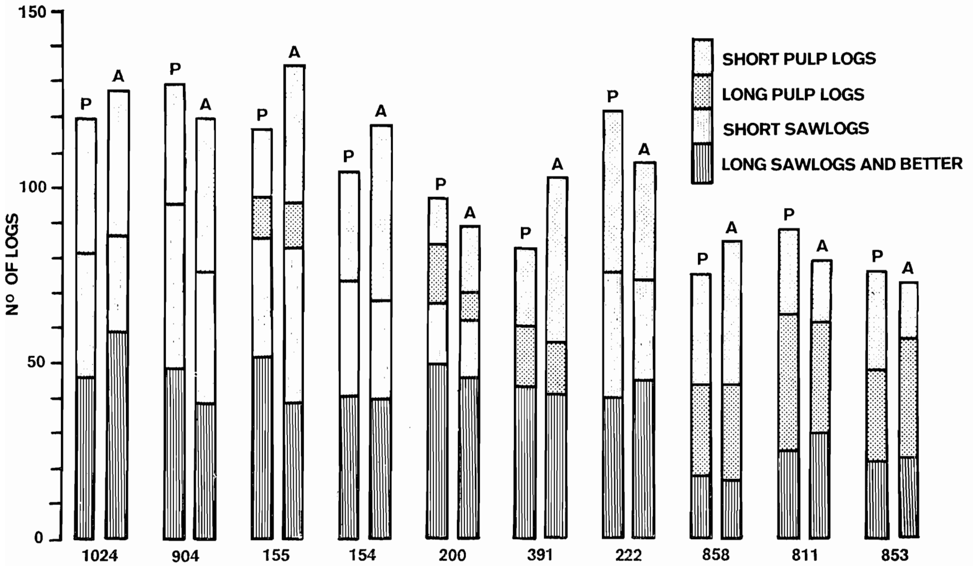


FIG. 3—Actual vs. predicted log counts
Total of 25 trees each compartment.
10 compartments Kaingaroa State Forest

explained if, with old crop radiata, the amount of waste left in the bush were a function of numbers of trees rather than total volume or tree size. All other correlation coefficients were highly significant, that of recovered volume being 0.94.

CURRENT IMPLEMENTATION

An operational system based on this assessment method has been implemented in the form of a computer package running on the Computer Services Division's ICL 2980 computer at Trentham, associated field and office forms, and a detailed users' reference manual covering inventory design, field method, and processing (Deadman and Goulding, 1978; unpubl. rep.).

Inventory

Each assessment begins with preparation of a plan defining the area to be assessed, the sampling method, the volume, taper and breakage functions selected from a standard library, and the quality classes to be used in cruising. This plan is summarised on a computer input form which eventually becomes the cover sheet for the inventory data.

Any of three stratification methods can be selected for an assessment in combination with any of three methods of plot demarcation. The combination chosen must, however, be used throughout the assessment. The stratification methods supported are:

- simple random sampling
- stratified random sampling with a common height/diameter equation derived for the entire population
- stratified random sampling with a separate height/diameter equation derived for each stratum.

The plot types supported are:

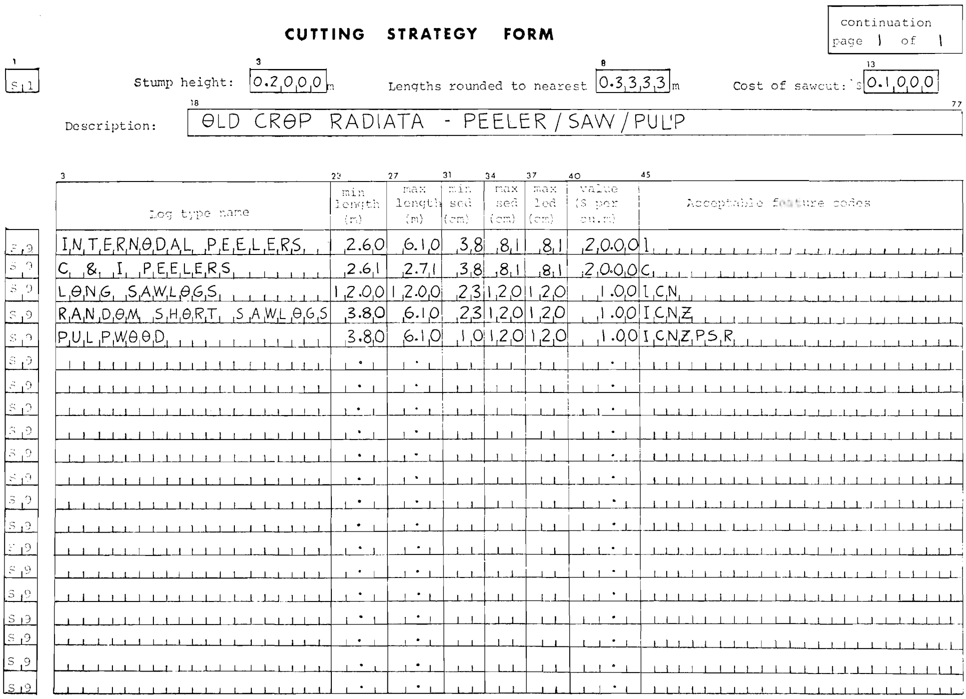
- bounded plots with every tree cruised and measured for d.b.h.
- angle gauge or prism points, with all trees included in the sweep being cruised and measured for d.b.h.
- double sampling with angle gauge or prism points. A proportion of the points are "tally plots" at which only a count of trees is recorded. At the remaining points the trees included in the sweep are measured for d.b.h. and cruised.

Field parties for inventory are typically of two to four persons, depending on the sampling method. Skilled staff are necessary for estimation of stem quality and dimensions. In particular, heights and lengths of features and upper stem diameters are usually estimated by eye, although frequent checks are being made using a Suunto hypsometer and Spiegel Relaskop for heights and diameters respectively. A light graduated pole is used also as a reference in estimation of heights and lengths. Measurements of d.b.h. are made with tape or calipers, the latter being preferred where out-of-round affects quality classifications. Total heights are normally obtained with the Suunto.

Processing

Assessment data are normally prepared using key to disc data entry equipment, and several data validation checks can be made at this stage. After punching the data are validated by a program which checks that data are in the correct order, that all measurements are within reasonable limits, and that the inventory is consistent with the original design. Very detailed checking is made of the recorded descriptions of trees; because the "language" used to describe features is very flexible, "grammatical" errors are expected from time to time. The data are listed with any comments, warnings or errors highlighted, and a scattergram is produced for each height/diameter regression to illustrate the sample values and the regression curve.

Each cross-cutting pattern is entered on a "cutting strategy" form suitable for key-punching directly to produce a cutting strategy file for use in analysis (Fig. 4). The main items of the cutting strategy are log type descriptions each consisting of a name, minimum small end diameter. maximum small end and large end diameters, a range of random and/or fixed lengths, quality class codes of all qualities permissible in logs of this type, and a value expressed in dollars per cubic metre. Other items in the strategy are the stump height for felling, the cost of making a sawcut, and an interval length for controlling the resolution of the dynamic programming algorithm.



CUTTING STRATEGY FORM

continuation page 1 of 1

1 S 1 Stump height: 3 0.2000 m Lengths rounded to nearest 8 0.3333 m Cost of sawcut: $ 13 0.1000

Description: 18 OLD CROP RADIATA - PEELER/SAW/PULP 77

	3 Log type name	23 min length (m)	27 max length (m)	31 min sed (cm)	34 max sed (cm)	37 max led (cm)	40 value ($ per cu.m)	45 Acceptable feature codes
S 9	INTERNODAL PEELERS	2.60	6.10	38	81	81	20.00	I
S 9	C & I PEELERS	2.61	2.71	38	81	81	20.00	C
S 9	LONG SAWLOGS	12.00	12.00	23	120	120	1.00	ICN
S 9	RANDOM SHORT SAWLOGS	3.80	6.10	23	120	120	1.00	ICNZ
S 9	PULPWOOD	3.80	6.10	10	120	120	1.00	ICNZPSR
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	
S 9		.	.				.	

FIG. 4—Example of a strategy specified by the user to control the simulation of cross-cutting.

Given a cutting strategy and the successful validation of the data, analysis can be carried out. The strategy itself is checked to ensure that it is reasonable and that all quality codes cited were defined in the inventory plan. The inventory plan, cutting strategy and details of all equations used are always printed out in full. The amount of detail printed during the analysis is otherwise controlled by the user and varies from a population summary to a piece by piece breakdown of each tree into logs. The popula-

MPT MARVL SYSTEM PROBLEM KANG0001 POPULATION SUMMARY

POPULATION : COMPARTMENT 392 ESTABLISHED 1929

DATE LISTED : 26/03/79
DATE CRUISED : 01/78
TOTAL AREA : 83.8 HA

CONSERVANCY: ROTORUA
FOREST : KANG
SPECIES : P.RADIATA

* * * STANDING RESOURCE * * *

TOTAL LIVE VOLUME : 1138.0 CU.M/HA
SE OF MEAN VOLUME : 52.7 CU.M/HA
SE OF MEAN VOLUME : 4.6% OF MEAN

POPULATION LIVE VOLUME: 95364 CU.M

LIVE BASAL AREA : 76.4 SQ.M/HA
LIVE STOCKING : 297.8 TREES/HA
DEAD STOCKING : 143.7 TREES/HA
NO. NON-MERCH LIVE TREES: 0.0 TREES/HA
% LIVE TREES MALFORMED : 11.2 %

MEAN TREE VOLUME (LIVE) : 3.822 CU.M
MEAN TREE HEIGHT (LIVE) : 44.42 M
MEAN TREE DBHOB (LIVE) : 55.15 CM
MEAN TREE DBHOB (DEAD) : 29.29 CM
MEAN TOP DIAM (100) : 70.66 CM
MEAN TOP HEIGHT (100) : 50.58 M

* * * FELLING RESIDUE * * *
(LIVE TREES ONLY)

VOLUME ABOVE BREAKPT : 101.0 CU.M/HA
VOLUME OF STUMPS : 13.2 CU.M/HA
VOLUME NON-MERCH STEMS: 0.0 CU.M/HA

MEAN TREE VOLUME ABOVE BREAK PT: 0.339 CU.M
MEAN TREE VOLUME OF STUMP : 0.044 CU.M
MEAN HEIGHT TO BREAK PT : 29.507 M

* * * HAULING INFORMATION * * *
(MERCHANTABLE TREES ONLY)

VOLUME EXTRACTED : 1023.8 CU.M/HA
NO. STEMS EXTRACTED : 297.8 STEMS/HA

MEAN EXTRACTED STEM VOLUME : 3.438 CU.M
MEAN EXTRACTED STEM LENGTH : 29.307 M

* * * TRIMMING INFORMATION* * *

NO. OF PIECES : 348 PCES/HA
(AFTER CUTTING FORKS & BRANCHES)

MEAN PIECE VOLUME : 2.941 CU.M
MEAN PIECE LENGTH : 26.377 M

* * * LOG PRODUCT MIX * * *

LOG TYPE	PER LOG		PER HECTARE			POPULATION TOTAL		
	VOLUME CU.M	VALUE $	LOGS	VOLUME CU.M	VALUE $	LOGS	VOLUME CU.M	VALUE $
INTERNODAL PEELERS	0.757	15.13	13	9.53	190.53	1055	798	15966
C.&I. PEELERS	0.495	9.91	916	453.60	9072.07	76723	38011	760239
LONG SAWLOGS	1.203	1.20	174	209.42	209.42	14587	17549	17549
RANDOM SHORT SAWLOGS	0.580	0.58	299	173.58	173.58	25077	14546	14546
PULPWOOD	0.304	0.30	381	115.92	115.92	31906	9713	9713
TOTAL RECOVERABLE			1782	962.05	9761.51	149350	80619	818015
S.E. OF MEAN RECOVERABLE				43.50			3645	
CUTTING PATTERN WASTE				61.79			5177	

FIG. 5—Population summary resulting from computer analysis.

tion summary contains details of the standing crop, felling residue (including non-merchantable trees), information relating to hauling and trimming, and log volumes and counts for each of the types in the strategy (see Fig. 5). Tables are produced for trees and volumes per hectare by d.b.h. class in various categories, and for number and volume per hectare of each log type, by small end diameter of logs (see Fig. 6 for the latter).

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* * *LOG TABLE PER HECTARE* * *

SED	INTERNODAL PEELERS NO.	INTERNODAL PEELERS VOLUME	C.&I. PEELERS NO.	C.&I. PEELERS VOLUME	LONG SAWLOGS NO.	LONG SAWLOGS VOLUME	RANDOM SHORT SAWLOGS NO.	RANDOM SHORT SAWLOGS VOLUME	PULPWOOD NO.	PULPWOOD VOLUME
8 +	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.1
12 +	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.9	8.7
16 +	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	114.1	21.7
20 +	0.0	0.0	0.0	0.0	9.6	7.5	17.0	5.2	114.1	30.0
24 +	0.0	0.0	0.0	0.0	49.6	48.1	84.4	29.5	20.7	7.8
28 +	0.0	0.0	0.0	0.0	82.2	93.9	51.9	22.5	17.8	8.4
32 +	0.0	0.0	0.0	0.0	17.0	23.5	62.2	34.3	13.3	7.8
36 +	1.5	0.7	151.1	50.9	6.7	11.9	20.0	13.7	7.4	5.3
40 +	3.7	2.5	242.2	94.5	3.0	6.5	19.3	15.9	10.4	7.9
44 +	5.2	3.9	193.3	90.8	3.7	9.1	13.3	12.2	5.9	5.6
48 +	1.5	1.7	146.7	81.1	0.7	2.2	9.6	10.2	4.4	5.2
52 +	0.7	0.8	84.4	54.6	0.0	0.0	8.9	12.1	4.4	5.1
56 +	0.0	0.0	52.6	39.5	0.0	0.0	7.4	10.2	1.5	2.3
60 +	0.0	0.0	26.7	23.1	1.5	6.6	3.7	4.8	0.0	0.0
64 +	0.0	0.0	10.4	10.0	0.0	0.0	0.7	1.8	0.0	0.0
68 +	0.0	0.0	6.7	7.3	0.0	0.0	0.7	1.2	0.0	0.0
72 +	0.0	0.0	1.5	1.8	0.0	0.0	0.0	0.0	0.0	0.0

FIG. 6—Log table resulting from computer analysis.

All processing is carried out in batch jobs. These are normally initiated centrally at present, but the implementation has been designed for use at remote sites by personnel who are not necessarily very familiar with computers: in fact a single command is used to control all processing options.

Portability

Use of the system outside the New Zealand Forest Service would require training of staff, development or adaptation of the volume, taper and breakage relationships using local data; and implementation of the computer programs.

Volume, taper and breakage relationships are available for a number of major species in New Zealand. The functional forms currently implemented are listed at the end of this section. Other forms could be used for these functions but the computer programs would have to be modified slightly. The form of the internally derived height/diameter regression used to estimate heights, is also listed.

There are two main programs written in COBOL and two small sub-routines written in FORTRAN. As far as possible ANSI 74 COBOL has been used but a few exceptions occur in the use of floating-point variables for communication with the FORTRAN routines and with standard mathematical routines for cosine, tangent, logarithm and exponent. There are about five thousand lines of source of which thirteen are FORTRAN.

The dynamic programming procedure used can require a huge number of iterations to find each optimum. For this reason considerable care has been taken to make this procedure as efficient as possible. Execution times vary considerably depending on the cutting strategy but about three minutes per thousand trees would be typical on the ICL 2980.

Form of functions used

Volume

(a) Logarithmic $\ln(V) = a_0 + a_1 \ln(D) + a_2 \ln\left(\frac{H^2}{H - 1.4}\right)$

or (b) Arithmetic $V = a_0 + a_1 D^2 H + a_2 D^2 + a_3 H$

Taper

$$d_l^{\,2} = \frac{a_0 V}{H}\left[a_1\left(\frac{l}{H}\right) + a_2\left(\frac{l}{H}\right)^2 + a_3\left(\frac{l}{H}\right)^3 + a_4\left(\frac{l}{H}\right)^4 + a_5\left(\frac{l}{H}\right)^5\right]$$

$$V_l = \int_0^l \frac{\pi}{4}\, d_l^{\,2}\, dl$$

Breakage

$$b = a_0 + a_1 H + a_2 H^2 + a_3 S + a_4 S^2 + a_5 SH$$

(additional parameters required are average proportion of trees breaking, and standard error of $\frac{b}{H}$).

Height

$$(H - 1.4)^{-0.4} = a_0 + a_1 D^{-1}$$

D is d.b.h. outside bark

H is total height

V is total volume inside bark

S is average ground slope

l is distance from tip

d_l is diameter inside bark at distance l from tip

V_l is volume inside bark cumulative from tip to l

b is height of break point

DISCUSSION

The need for suitable volume, taper and breakage functions which are applicable to the stands being inventoried may be an obstacle to use of the system. A long-term solution to this may lie in combining features of the present method with the use of 3-P sampling and dendrometry for volume measurement.

Further work on a more elaborate breakage model may not be very rewarding, as important influences include logging personnel and variability of ground conditions within the stand, neither of which may be predictable. No attempt has yet been made to project the inventory results a short time (five to ten years) into the future. If it is possible at the time of inventory to collect quality and malformation information which will be valid for the end of the projection period, a simple approach would be to grow the basic inventory data before analysing in the normal way.

Successful application of the system depends on appropriate definition of quality classes, as these form the interface which links each cutting strategy to the inventory whilst making the field data largely independent of log specifications. Flexibility in analysis requires careful consideration of the possible types of strategies when defining the classes; relevance of the results depends on accurate and objective definition of log quality requirements. An unexpected effect of use of the system has been a critical re-examination of quality specifications of high value logs. These specifications are sometimes couched in imprecise terms which are as unsatisfactory for cruising as they are for logging.

Suggested areas of application for the system have included evaluation of tree improvement programmes, where the value of log outturn could provide an objective measure of improvement. At the opposite extreme, it is possible to carry out an assessment without recording any quality or malformation information and allow log dimensions and values alone to determine the product yield; this approach could be used to analyse data obtained from growth models, management inventory or permanent sample plots.

As originally conceived the system was for use in pre-harvest assessments, where it was felt that its advantages would lie not so much in accurately predicting log yield as in providing data to plan the efficient use of available timber resources. The system and its prototype have already been used for a wide variety of stands and cutting patterns. Some of the applications for which experience has been obtained are: the determination of high value peeler logs from *P. radiata*; export sawlogs, local sawlogs and pulpwood from Douglas fir and *Pinus* spp.; posts from young *P. nigra*; high value poles from mature *P. nigra*; and merchantability of *P. ponderosa* pulpwood stands. The flexibility of the system with regard to altering log specifications and the detail produced in the output are new to forest managers in the Forest Service. It is felt that once they become familiar with the method's capabilities and the information produced, it will prove an invaluable tool and the number and variety of applications will go beyond what were originally envisaged.

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