# WORK STUDIES OF CUTTING IN RADIATA PINE

by

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Except where otherwise acknowledged, this thesis is the author's own original work.

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# CHAPTER 1

# INTRODUCTION

Costs of logging and hauling to the mill are important for the wood using industries in Australia. These costs constitute as much as 80 per cent of the cost of pulpwood delivered to the mill (Cromer, 1970) and 64 per cent of the cost of sawlogs delivered to the mill (Report of the Economic Study Group on the Australian Timber Industry, 1971).

Although some valuable studies of the productivity of logging and hauling operations have been made, the Economic Study Group on the Australian Timber Industry revealed how little the local timber industry itself has done:-

> ...when asked in the questionnaire if any comparative cost studies had been undertaken, not one of the 120 firms which returned the questionnaire replied in the affirmative.
>
> Discussions which the Study Group had with many saw-milling interests brought forth the same reaction - the practices followed on log extraction reflected at best an informed opinion but were seldom based on any detailed cost studies. (Report of the Economic Study Group on the Australian Timber Industry, 1971, p.32).

One reason for the lack of comparative studies by the industry is a dearth of published articles describing study techniques suited to local conditions and illustrating the questions which can be answered. This thesis shows how work study techniques have been used to solve some problems typical of these found in Australian logging.

Determining the best logging method for a given area is a common problem. The first part of this thesis compares two methods of logging first thinnings, the shortwood and tree length methods, with special reference to their application in the Bathurst plantations, New South Wales. Although the results of this study may only be of local interest, the procedures used will provide guidance for further research into this and related problems in the Australian logging industry.

To solve a good many problems in logging, information on the productivity, (output per unit working time) of logging operations is required, which may have to be obtained by time study. The second part of this thesis deals with effects of differences between stands on the productivity of sawlog cutting operations in New South Wales and the Australian Capital Territory.

Because time and manpower were limited, fieldwork for the thesis was confined to one component of the logging operation only, namely cutting. Cutting is here defined as felling and all other work performed on felled trees to prepare them for removal from the forest to the main road. It was decided to concentrate on cutting in pine plantations because of the growing importance of such plantations in Australian forestry. About 15 per cent of the total roundwood removals from Australian forests in 1968 came from coniferous plantations, (Wilson, 1969) but recent forecasts suggest that this fraction will steadily increase to about 30 per cent by the year 2000 (Hanson and Farrow, 1969; Report of the Economic Study Group on the Australian Timber Industry, 1971).

Shortwood and tree length logging

In most coniferous plantations yields from first thinnings are increasing steadily and will continue to do so for many years. However, the productivity of cutting and extraction is much lower in first than in later thinnings. Priority should therefore be given to comparative studies of logging methods for first thinnings.

The shortwood logging method is widely used in first thinnings. Typical of such operations are those in pine plantations near Bathurst owned by the Forestry Commission of New South Wales. The merchantable stem of each felled tree is cut up at stump into billets eight feet long which are extracted to roadside by various means, described later. It has been claimed, however, that tree length logging operations, in which the entire merchantable stem of each felled tree is extracted to roadside as a single log, cost 10 per cent less than shortwood operations in first thinnings and require less labour (Kerruish, 1968).

The aim of the study was to compare the two methods in terms of the cost per unit volume for cutting and extraction to roadside in the Bathurst plantations. The effect of a change from shortwood to tree length logging on future plant and labour requirements was also investigated.

Studies were made of shortwood cutting at Sunny Corner, one of the Bathurst plantations. The data collected were also used to construct a simulation model of cutting operations involved in tree length logging. The use of a simulation model avoided the need for expensive field trials and has many potential applications in comparative studies of logging methods. Data on extraction were largely obtained from earlier studies. Some supplementary studies were also made.

## Studies of sawlog cutting

The studies in the second part of this thesis had two aims; firstly to investigate by time study the effects of differences between stands on the productivity of sawlog cutting operations, secondly to compare two alternative time study techniques.

### Effects of stand differences on cutting productivity

Previous work studies of cutting by Hasel (1946), Guttenberg and Perry (1957), Samset (1950) and Samset et al (1969) had clearly shown that the productivity of cutting operations is affected by stand variables such as the basal area and number of trees removed per acre, their form and spacing.

These relationships have implications for wage determinations when cutters are paid by results, as is usual in Australia. Some cutters are paid under the terms of industrial awards and, assuming an equitable piece rate has been established for cutting in a given stand, it would be desirable for their employer to make any necessary adjustment to the piece rate when they move to a different stand. The adjustment should ensure no cutter who works the required hours receives less than the minimum weekly wage dictated by the award.

Many cutters, however, negotiate directly with their employers over wage rates. The productivity of cutting is a factor to be considered but many other factors such as supply and demand for labour, security of employment, equipment supplied and living conditions are also important. A study of cutting productivity can only provide suggestive data for wage negotiations since the prevailing conditions of employment affect the average level of performance. Nevertheless, such a study could provide a better basis for ensuring wage equity between cutters working in different stands and for determining wage justice in relation to average productivity.

Time studies were made of twenty four sawlog cutting operations in pre-war plantations in New South Wales and the Australian Capital Territory. Each operation was studied in the compartment scheduled to be cut when the study took place.

## Time study techniques

Two different time study techniques had been used in previous studies of cutting. Samset (1950) and Samset et al (1969) used a technique called "Detailed" time study in which each operation is subdivided into a number of component elements, which are then studied individually. An alternative technique, called "Gross Data" time study, in which each operation is studied as a whole or subdivided into as few elements as possible was used by Hasel (1946), Guttenberg and Perry (1957), and in studies of log extraction made by Bennett et al (1965). Gross Data time study should cost less than Detailed time study but the latter may give more precise results if an operation is composed of several separate sub-operations.

When the component elements in a Detailed time study are finally aggregated to construct a predictive model of the whole operation, it is assumed the elements are independent of each other. Results of experiments conducted by Nanda (1968) suggest this assumption may be valid for various light industrial operations. It may not, however, be valid for heavy sequential work such as cutting.

Bennett et al discussed the effect of element independence on the relative precision of Detailed and Gross Data time studies:

> If these sub-processes (elements) are essentially independent of each other, then their combined error variances in a "gross" model may obscure or obliterate real effects of condition factors (e.g. stand, terrain and climatic variables) on one or more sub-processes. However, this is not the only possibility. ...The sub-processes may not be truly independent of one another, and the sum of the sub-process estimates may therefore prove to be no better than an overall estimate from a gross model. This question deserves further study. (Bennett et al, 1965, p.11).

The question received further attention in a study by Cottell and Winer (1969). They compared results obtained by Detailed and Gross Data time studies of the same extraction operation and found no differences of practical importance. They concluded that Gross Data time study could provide sufficient information for the management of established logging operations but Detailed time study could provide extra information needed for critical or comparative studies of logging methods.

Detailed time study techniques were used in studies of shortwood cutting operations for the first part of this thesis because information on several component elements of shortwood cutting was needed for constructing a simulation model of tree length cutting. In the second part of the thesis, however, both Detailed and Gross Data time study techniques were used to study the effects of differences between stands on sawlog cutting productivity. The two techniques were compared in terms of precision and the ratio of total study cost to precision.

## Work study procedures

General procedures outlined by the International Labour Office (Introduction to Work Study, 1962) were followed in time studies made for this thesis. One aspect of these procedures needed special treatment for forestry, however, namely performance rating. This is commonly used in time studies of industrial operations to take account of deviations in the performance of a given worker from the average performance for the group under consideration, and is defined as

> ...the mental comparison by the work-study man of the performance of an operator under observation with his own idea of a standard performance for a given method. (Introduction to Work Study, 1962, p.231)

Performance rating is obviously a subjective process and the work study man would need to rate every element performed during the study.

In heavy manual work such as cutting, performance is very variable. Not only do cutters have different performance capacities depending on their physique, skill and experience but the performance of each individual cutter varies during the day and from day to day throughout the year (Samset et al, 1969; Makkonen, 1954). These variations reflect differences in health and temperament and in the environment. The way cutting is organized in Australia may also affect performance levels. Most cutters are paid by results and, theoretically, work under the stimulus of an incentive wage payment plan but in practice restrictive quotas are often imposed on their output by the grower or buyer. Some cutters may deliberately adjust their performance level when a time study commences, but it is likely they would gradually resume their normal rhythm of work.

The Nordic Forest Work Study Council has advised that if performance rating is to be used at all in forestry, then it should only be done by those who subsequently use and interpret the results (Skogligarbetsstudienomenklatur, 1963). There are usually four parties concerned with sawlog cutting in Australian pine plantations: the grower, the buyer, logging contractors hired by the grower or buyer, and cutters employed by the contractors. Studies in this thesis were undertaken to provide information for use by any of these parties so the services of an independent work study officer, with considerable experience of cutting work, would have been required to provide accurate and acceptable performance ratings. However, even if such ratings were desirable, no one qualified to do it was available.

Performance ratings are used to correct the observed time for each element to the "normal time" by the relationship

$$\text{Normal time} = \frac{\text{Observed time x performance rating}}{\text{Rating for normal performance}}$$

Kilander (1958) raised a strong objection to the use of performance rating in forestry, pointing out that bias could easily be introduced in correcting observed times to normal times because the forest environment is very variable. Since performance level fluctuations are an important source of variation in observed times, bias introduced by performance rating would largely negate the analysis of time study data by statistical methods. For this reason performance rating was not used in the studies for this thesis in order that regression analysis might be used to study the effects of differences between stands on the productivity of cutting.

A further problem in work study procedure was estimating the time required for rest and meal breaks when cutters recover from fatigue. Several aspects of cutting work may induce fatigue; awkward working positions, the continual use of force and muscular energy and intermittent loud high-pitched noise and vibration from chain saws. The time required for rest is an important consideration when setting time standards because the time allowed should be adequate, but not excessive, for the essential needs of the cutters.

Tables of rest allowances for industrial environments are available (Introduction to Work Study, 1962) but have not yet been tested in Australian forests. Meal breaks are often prescribed for industrial workers but piece work cutters are free to determine if and when they require breaks. The observed times for rest and meal breaks were therefore used throughout the studies in this thesis, without considering whether they reflect the essential needs of cutters or not.

# PART I

# COMPARING LOGGING METHODS

# CHAPTER 2

# STUDIES OF SHORTWOOD LOGGING

## Shortwood extraction

In Australian coniferous plantations trees are planted in rows, generally eight feet apart. In the first thinning entire rows of trees (called outrows) are removed at regular intervals to allow machines used for log extraction to enter the stand. Other trees are removed selectively from the bays between the outrows.

In shortwood cutting operations, billets are cut from each felled tree, carried to the outrow and stacked there for subsequent extraction. In some plantations, such as those near Mount Gambier, South Australia, shortwood billets are loaded onto road trucks which enter the stand along the outrows and haul directly to the mill. Road trucks cannot enter the outrows in the Bathurst plantations because ground conditions are unsuitable. One of three methods might then be used to extract billets to roadside where they would be transferred to road trucks:

(a) Blitz trucks with pallets

(b) Forwarders

(c) Skidders

Each method of extraction would require a different method of stacking by the cutters.

In the 1950's and 1960's ex-army blitz trucks were widely used in the Bathurst plantations for extracting first thinnings. Cutters were required to stack their billets in metal pallets which, when filled, were winched onto the tray of the blitz truck and carried to roadside. Blitz trucks were not studied for this thesis, however, because in recent years better and more economical methods have been developed for shortwood extraction. These methods employ articulated, rubber tyred machines with four wheel drive and excellent traction, even on slippery or boggy ground. Because the machines can load from loosely piled stacks, cutting and extraction are less dependent on each other than they used to be when pallets were used.

At Canobolas, one of the Bathurst plantations, shortwood billets are extracted with a skidder equipped with a loading boom and winch. Cutters stack about seventy cubic feet true volume within a light frame and bind the stack with wire before removing the frame. The winch rope of the skidder, which runs over a pulley at the top of the loading boom, is pulled out, passed around the stack and fastened with a choker. The stack is winched clear of the ground, tucked in over the rear wheels of the skidder and carried to roadside. Similar operations at Longford plantation, near Traralgon, Victoria, have been studied by the Forestry and Timber Bureau of Australia. The Bureau's data were used to determine the average machine and labour productivity of a skidder (Table 1, page 13).

Kerruish (1970) has suggested that forwarders could provide efficient means of extracting shortwood billets, a forwarder being an articulated, rubber tyred, four wheel drive tractor with an integral load carrying cradle and a hydraulic grab loader. Forwarders can load efficiently from stacks containing as little as ten cubic feet (Stickvågs huggning vid traktorkörning, 1963) and can stockpile billets at roadside or transfer them directly onto roadtrucks. Two shortwood extraction operations with forwarders of 42 horsepower (H.P.) have been studied by the Forestry and Timber Bureau. One was at Gurnang, one of the Bathurst plantations and the other was at Gnangara plantation, near Perth, Western Australia. Billets eight feet long were extracted in both these operations. The Bureau's data were used to determine the average machine and labour productivity of a 42 H.P. forwarder (Table 1).

TABLE 1

Productivity in shortwood extraction operations

| Method | Average machine productivity (cubic feet per machine hour) | Average labour productivity (cubic feet per man hour) |
|---|---|---|
| 97 H.P. skidder | 1340 | 494 |
| 42 H.P. forwarder | 404 | 309 |

The machine productivity is the output per unit of time when the motor works at full power. The labour productivity is the output per unit of time when the operator is engaged in actual extraction or resting during or after extraction. Because the operators' rest and meal breaks were not adequately sampled during the studies, an allowance equal to a quarter of the time spent on actual extraction was made for rest and meal breaks.

The Bureau's data suggested skidders would be more economical than forwarders for extracting shortwood billets in first thinnings at Bathurst but larger stacks would be required for skidders than for forwarders.

Studies of cutting

Earlier studies of cutting in first thinnings in Australia indicated some of the problems involved in studying shortwood cutting and comparing it with alternative methods such as tree length cutting. None of the earlier studies was conducted in a thoroughly rigorous manner so the results themselves were of doubtful value.

The Forestry and Timber Bureau made detailed time studies of three selected cutters in the Bathurst plantations (Anon, 1965). All observed times were corrected by a performance rating process and a subjective allowance was made for the time spent on rest and meal breaks. Each cutter's total corrected time was divided by his volume output and the average of all three cutters' times determined. This average time per unit volume corresponded to a productivity of 29 cubic feet per man hour for shortwood cutting. The average corrected time per unit output for each element of the shortwood cutting operations was also calculated. Times for the elements "trimming" and "measuring" had to be estimated for one cutter because he performed these elements together and they were not distinguished separately in the time study. The average times for measuring, crosscutting and stacking were subtracted from the average total time to construct a simulation model of tree length cutting. The simulated time per unit volume corresponded to a productivity of 49 cubic feet per man hour for tree length cutting.

Kerruish (1967) discussed differences between shortwood and tree length logging with respect to safety, and their implications for forest management, millyard handling and recovery, and gave results of studies of shortwood and tree length logging operations in the Bathurst plantations. Observed times for shortwood cutting were compared with corrected times for tree length cutting covering a range of values of mean volume per removed tree. No details of the sampling procedures or time study techniques were given.

Hill (1966) published tables of standard times per unit volume output for cutting pulpwood billets six feet long in the East Gippsland plantations of A.P.M. Forests Pty. Ltd.. These data may be applied to distributions of breast height diameters and merchantable lengths among trees removed from representative stands to determine the productivity of cutting. The effects of these tree characteristics on cutting time may, however, have been biased because a performance rating process was used in the study. Times per unit output given for component elements of shortwood cutting could be used to construct a simulation model of tree length cutting but, again, these may have been biased by the rating process.

Whiteley (1967) studied three shortwood cutters in several different stands at Sunny Corner, one of the Bathurst plantations. Effects of stand differences on time per unit output for each element of the cutting operation were investigated by regression analysis. Performance rating was not used. Whiteley stressed his results should be treated with caution because adequate data were gathered on only one of the cutters. Data on this cutter showed mean volume per removed tree affected the time per unit output for several elements. The volume removed per acre and density of hardwood debris affected some elements but had only a slight effect on cutting productivity overall. The productivity of cutting and stacking increased by about 16 per cent when stacks containing fifteen instead of sixty cubic feet were prepared. Only the larger stacks were suitable for extraction by skidders but either size of stack could be extracted by forwarders.

Further studies of shortwood cutting in first thinnings were arranged by the author at Sunny Corner. Since earlier cutting studies had indicated that differences between stands in the mean basal area per removed tree, caused by variations in spacing, survival and rate of growth, could affect the productivity of cutting, three areas were chosen in compartments scheduled for thinning at the time the study was made. One area was typical of exposed ridge sites where the mean basal area per removed tree ranged between 0.18 and 0.20 square feet. As such areas were limited in size, parts of two separate compartments were required to provide sufficient material for the study. The second area was typical of sheltered, well drained sites where the mean basal area per removed tree ranged between 0.25 and 0.30 square feet. The third area was intermediate in terms of site quality.

Three cutters were studied. Each cutter used a chain saw for felling and docking (i.e. crosscutting billets), an axe for trimming and a light measuring stick for measuring billets. Billets were cut to a merchantable small end diameter of about four inches overbark. Cutter 1 felled ten to fifteen trees at a time, successively trimmed, measured and docked them and finally stacked the billets. Cutter 2 felled more trees at a time than Cutter 1 and combined the trimming and measuring. Cutter 3, having felled a tree, immediately measured and docked billets from it. Having done this to several trees, he trimmed and stacked the billets. The work methods used by Cutters 1 and 2 were basically similar but differed radically from the method used by Cutter 3. Both methods were used by other shortwood cutters in first thinnings.

Trees at Sunny Corner had been planted in rows eight feet apart and every tree had been pruned to a height of eight feet before the first thinning. Every ninth row was removed as an outrow in the first thinning and each cutter took an outrow and thinned four rows in the bays on either side. Stacks were made beside the outrow and sited where the hydraulic grab loader of a forwarder could grasp billets without hindrance from standing trees or logging slash.

Each cutter was studied in all three areas. Because alternative methods of shortwood extraction have different requirements with respect to stack size, and the results of an earlier study (Whiteley, 1967) indicated stack size might affect cutting productivity, each cutter was studied for three days in each area and instructed each day to make stacks of a particular size. The stack size for one day was about 20 cubic feet, for another day about 40 cubic feet and for the third day about 70 cubic feet. The shortwood cutting operations were subdivided into elements for Detailed time study (Table 2). Most of the elements are self explanatory but definitions are given in Appendix A. The time spent on each element was measured to the nearest one hundredth of a minute with a stopwatch having a split, fly-back hand.

The breast height and merchantable small end diameters of each removed tree were measured to the nearest tenth of an inch with calipers. After the time study, the heights of five remaining trees in the plot, subjectively chosen as the tallest, were measured. The mean height of the three tallest of these five trees was used as an estimate of the predominant height of the stand. A tree volume equation for radiata

TABLE 2

Elements of shortwood cutting operations

| Sub-operation | Element | Symbol |
|---|---|---|
| Felling | Collect tools | 1 |
| | Walk to tree | 2 |
| | Clear debris from base of tree | 3 |
| | Inspect and prepare to fell | 4 |
| | Saw | 5 |
| | Remove splinters from butt of felled tree | 6 |
| | Delays | 7 |
| Trimming | Collect tools | 8 |
| | Walk to tree | 9 |
| | Trim branches | 10 |
| | Delays | 11 |
| Measuring | Collect tools | 12 |
| | Walk to tree | 13 |
| | Measure billet lengths | 14 |
| | Delays | 15 |
| Docking | Collect tools | 16 |
| | Walk to log | 17 |
| | Crosscut | 18 |
| | Delays | 19 |
| Stacking | Collect tools | 20 |
| | Walk to billet | 21 |
| | Pick up billet, carry to stack and put down | 22 |
| | Trim branch stubs left on billet | 23 |
| | Delays | 24 |
| Miscellaneous | Clear slash from outrow | 25 |
| | Cut and clear hardwood debris on outrow | 26 |
| | Chain saw maintenance | 27 |
| | Rest and meal breaks | 28 |

pine, prepared by the Forestry Commission of New South Wales (page 53 ) was used to estimate the underbark merchantable volume of each felled tree. The equation uses breast height diameter, merchantable small end diameter and the predominant height of the stand as independent variables. The total volume felled in each study plot was divided by the number of stacks prepared to determine the mean stack volume.

Results of the cutting studies

For each study plot, the time spent on each element of the shortwood cutting operation was divided by the number of trees felled and the results for all the elements except "avoidable delays", which were excluded because they constituted time spent on operations other than cutting, were summed to obtain the mean cutting time per tree. Appendix B contains the element times, mean basal area per removed tree and mean stack volume for each study plot.

A regression of mean cutting time per tree on mean basal area per removed tree and mean stack volume was calculated for each cutter. The regression equations were:-

$$T = 2.44 + \underset{(\pm\ 5.29)}{19.53\,A} - \underset{(\pm 0.0092)}{0.0042\,S} \quad \text{for Cutter 1}$$

$$T = -2.01 + \underset{(\pm\ 7.20)}{28.73\,A} + \underset{(\pm 0.0105)}{0.0043\,S} \quad \text{for Cutter 2}$$

and

$$T = -9.01 + \underset{(\pm\ 9.98}{60.15\,A} + \underset{(\pm 0.0102)}{0.0516\,S} \quad \text{for Cutter 3}$$

where T denotes the mean cutting time per tree in minutes
A denotes the mean basal area per removed tree in square feet
S denotes the mean stack volume in cubic feet.

Mean basal area per removed tree had a significant effect on the work of all three cutters but mean stack volume only had a significant effect on the work of Cutter 3.

Covariance analysis with dummy variables (Freese, 1964) was used to test differences between the regressions. Tests described in Appendix C showed differences between constants and coefficients in the regressions were significant. Inspection of the regressions showed those for Cutters 1 and 2 were similar but differed markedly from that for Cutter 3. Results of a study of cutting in first thinnings in South Australian pine plantations (Whiteley, 1972) provided limited evidence to suggest that the differences in cutting times between Cutters 1 and 2, and Cutter 3 at Sunny Corner could not be explained by their alternative work methods.

Two South Australian cutters had been studied in the same stand. They had both used the same method to cut and stack random length billets and spent 4.34 and 4.65 minutes per tree respectively, suggesting they were equal in performance at cutting. Each cutter was also studied while cutting shortwood billets four feet long. The first cutter used the same method as Cutter 1 at Sunny Corner and spent 7.79 minutes per tree; the second used the same method as Cutter 3 at Sunny Corner and spent 7.56 minutes per tree. These results suggested that cutters would attain the same cutting time per tree with either method of shortwood cutting.

Although significant differences were found in the above regressions, probably caused by performance differences between cutters, an expression of the average effects of mean basal area per removed tree and mean stack volume on mean cutting time per tree was required. To obtain it, observations on all three cutters were pooled and a single regression computed. Mean stack volume was not significant and was dropped from the regression. The final regression equation was

$$T = -0.82 + \underset{(\pm\ 7.92)}{30.01\,A}$$

(using the same symbols as above). This equation was used as a predictive model of the working time involved in shortwood cutting in a first thinning in any of the Bathurst plantations. Cutting productivity for a stand could be estimated by dividing the volume yield by the predicted working time.

CHAPTER 3

# STUDIES OF TREE LENGTH LOGGING

## Simulating tree length cutting

To avoid costly field trials of tree length cutting, a simulation model was constructed from the data on shortwood cutting. Tree length cutting involved felling trees, trimming the branches and docking the unmerchantable top of each felled tree to obtain a single log from the merchantable stem. It is roughly equivalent to the work involved in felling and trimming in shortwood cutting operations. If the merchantable top diameter were 4 inches or less, the unmerchantable top of each felled tree could easily be docked by axe during trimming.

To construct a simulation model, it was assumed that the mean time per tree for each element of tree length cutting shown in Table 3 (page 24 ) would be the same as the mean time per tree for that element in shortwood cutting. It was also assumed that the time for docking unmerchantable tops would be negligible.

Chain saw maintenance would be much less than for shortwood cutting because docking would be eliminated. For convenience it was assumed that half the mean time per tree for chain saw maintenance in shortwood cutting would be required in tree length cutting. Tree length cutting would also reduce physical fatigue in cutters because strenuous billet carrying and stacking work would be eliminated.

However, tree length cutting might be more monotonous than shortwood cutting because less sub-operations are involved. It was assumed, therefore, that the fraction of working time spent on rest and meal breaks would be the same in tree length cutting as in shortwood cutting.

TABLE 3

Elements of tree length cutting common to shortwood cutting

| Sub-operation | Element |
|---|---|
| Felling | Collect tools |
| | Walk to tree |
| | Clear debris from base of tree |
| | Inspect and prepare to fell |
| | Saw |
| | Remove splinters from butt of felled tree |
| | Delays |
| Trimming | Collect tools |
| | Walk to tree |
| | Trim branches |
| | Delays |
| Miscellaneous | Clear slash from outrow |
| | Cut and clear hardwood debris from outrow |

Mean times per tree for the elements of tree length cutting were taken from the data on shortwood cutting in each study plot at Sunny Corner (Appendix B). Mean times per tree for all such elements in each plot were added together and a regression of the mean time per tree for simulated tree length cutting on mean basal area per removed tree was calculated from the pooled data on all plots. The regression equation was:-

$$T = -1.18 + \underset{(\pm 5.42)}{20.85}\,A$$

where T denotes mean cutting time per tree in minutes
A denotes mean basal area per removed tree.

This equation was to be used as a simulation model of the working time involved in a first thinning in any of the Bathurst plantations. It could be compared with the predictive model of shortwood cutting (on page 22) because it was based on the same sample of cutters.

Tree length logging at Tumut

Studies were made of tree length logging operations in first thinnings in pine plantations near Tumut, New South Wales. Data collected at Tumut were used partly to test the simulation model of tree length cutting and partly to determine the productivity of tree length extraction operations at Tumut.

At Tumut logs between 18 and 36 feet long are cut to a 4 inch merchantable small end diameter overbark. Cutters estimate the merchantable length of each felled tree by eye; if it is 36 feet long or less, a tree length log is cut, otherwise two or more logs having random lengths within the specified limits are cut. The method used at Tumut may therefore be described as long, random length logging but it is very similar to true tree length logging since trees from first thinnings are often not long enough to make more than one log.

Most cutters at Tumut use chain saws for trimming. They are all self-taught and do not use the safest or most efficient techniques. Every tree is pruned to a height of eight feet before the first thinning.

Cutters are required to bunch their logs in an outrow. Horses, winches mounted on agricultural tractors, and motor powered winches mounted on sleds are used for bunching. If horses are used, trees are felled tip first towards the outrow and logs snigged tip first to the bunch. All slash and hardwood debris must be cleared from the outrow to allow the horse to manoeuvre. If winches are used for bunching, trees are felled into the bays between outrows to keep the tops out of the outrows. Enough logs to make up a bunch are cut and then winched into the outrow, butt first. The winch is then moved through the unthinned stand to the site of the next bunch. A tractor mounted winch can be driven through the stand and a sled mounted winch can pull itself to an anchor tree. Bunches are subsequently snigged out to roadside by skidders.

Cutting studies at Tumut

Nine cutters (numbered from 4 to 12 hereafter) working singly in tree length operations at Tumut were studied. Five of these cutters, who used tractor mounted winches for bunching, were studied at cutting and bunching. The other cutters, who used horses for bunching, were studied at cutting only. The operations were subdivided into suitable elements for time study (Table 4).

TABLE 4

Elements of tree length cutting operations at Tumut

| Element |
| --- |
| Cut (including unavoidable delays associated with cutting) |
| Bunch (including unavoidable delays associated with bunching) |
| Rest and meal breaks |
| Avoidable delays |

The sequence of elements performed by each cutter was studied for one day and the time spent on each element measured. The breast height and merchantable small end diameters of the removed trees were measured and the predominant height in each study plot was estimated as before. The volume of each removed tree was estimated from the tree volume equation prepared by the Forestry Commission of New South Wales (page 53 ).

Where a cutter performed cutting and bunching, the total time spent on rest and meal breaks during the study was subdivided. Cutting and bunching were assumed to be equally strenuous activities. The time required for rest during cutting $R'$ was estimated from the total time spent on rest and meal breaks $R$, the time spent on actual cutting $C$ and the time spent on actual bunching $B$.

$$R' = R \times \frac{C}{C + B}$$

The estimated time required for rest and meal breaks during bunching was R - R′. Data collected at Tumut are given in Appendix D. Times for avoidable delays have been excluded.

Each cutter's hourly cutting output during the study was plotted against his average weekly cutting and bunching output for the four weeks after the study (Figure 1). The two measures of productivity were fairly well correlated but Cutter 11, who had the highest output per week after the study, had only the sixth highest cutting output per man hour during the study. This suggested his performance during the study was worse than normal and in fact he had just returned to work after treatment for a back injury.

## Testing the simulation model

Times spent on cutting and rest and meal breaks during cutting in each study plot at Tumut were added together and divided by the number of removed trees to determine the mean cutting time per tree. The equation on page 25 was used to simulate the mean time per tree for tree length cutting in stands with the same mean basal area per removed tree as each study plot at Tumut. The simulated mean cutting time per tree was subtracted from the actual mean cutting time per tree to obtain the difference for each plot. The differences and other data are shown in Table 5.

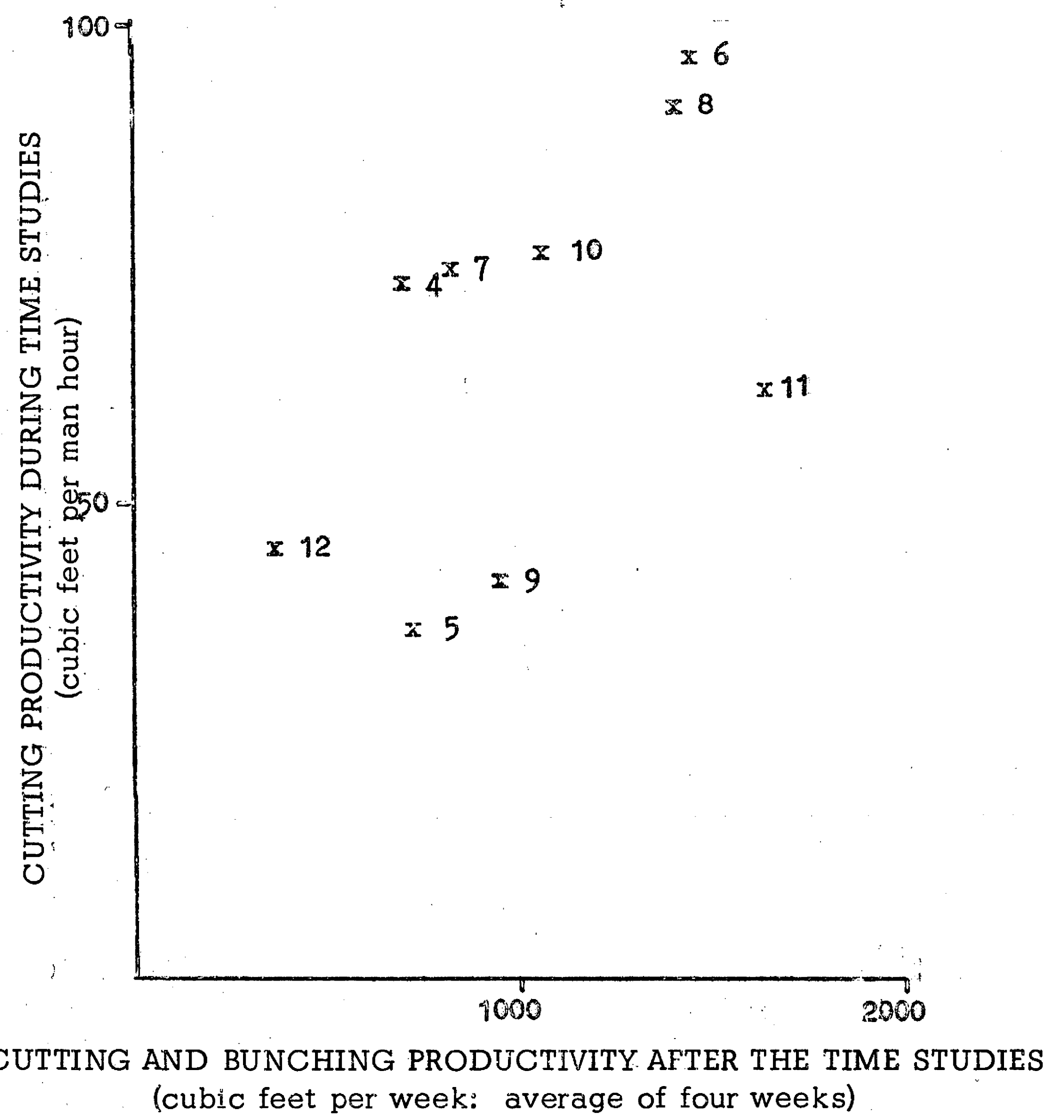


FIGURE 1

THE PRODUCTIVITY OF CUTTING OPERATIONS AT TUMUT
(individual cutters are identified by numbers; see page 26)

TABLE 5

Data for testing the simulation model of tree length cutting

| Cutter | Mean basal area per removed tree (square feet) | Actual cutting time (minutes per tree) | Simulated cutting time (minutes per tree) | Difference (minutes per tree) |
|---|---|---|---|---|
| 4 | 0.25 | 3.07 | 4.03 | -0.96 |
| 5 | 0.28 | 7.86 | 4.66 | +3.20 |
| 6 | 0.37 | 4.11 | 6.53 | 2.42 |
| 7 | 0.45 | 7.46 | 8.20 | -0.74 |
| 8 | 0.28 | 3.02 | 4.66 | -1.64 |
| 9 | 0.26 | 6.23 | 4.24 | +1.99 |
| 10 | 0.35 | 5.19 | 6.12 | -0.93 |
| 11 | 0.30 | 5.04 | 5.08 | -0.04 |
| 12 | 0.35 | 7.31 | 6.12 | +1.19 |
| Mean difference | | | | -0.05 |
| Standard Error | | | | ±0.61 |

The mean difference was divided by its standard error and compared with tabulated values of Student's t - statistic. The mean difference was not significant at the 95 per cent level of probability so the simulation model would provide satisfactory estimates of the working time required for cutting in actual tree length operations.

The simulation model was based on data on axe trimming but the test data from Tumut were based on chain saw trimming. Comparative studies of axe and chain saw trimming in Sweden by Ager (1964) suggested the working time per tree required for chain saw trimming might be less than for axe trimming but any difference should be negligible in first thinnings. Cutters at Tumut had also to crosscut some of their tree length logs into random length logs which would be unnecessary in true tree length operations.

Tree length extraction

Two methods of tree length extraction in common use in first thinnings at Tumut have been briefly discussed above (pages 25 & 26). Either could be used for first thinnings in the Bathurst plantations but there are other possibilities as well. Listed below are four possibilities including the two used at Tumut:

(a) snigging to roadside with horses

(b) bunching in the outrows with horses and subsequently extracting the bunches to roadside with skidders (as at Tumut)

(c) bunching in the outrow with motor powered winches and subsequently extracting the bunches to roadside with skidders (as at Tumut)

(d) Snigging to roadside with specially equipped industrial tractors.

Snigging or bunching with horses

If tree length logging were introduced at Bathurst, it is unlikely horses would be used for snigging or bunching. Present contractors in first thinnings use machines for extraction and would no doubt continue to do so. Horses are not used in any other logging operations at Bathurst and would need to be reared, broken in and trained if obtained from elsewhere.

Bunching with winches, bunch extraction with skidders

Motor powered winches are widely used in first thinnings at Tumut for bunching logs in the outrows. Although limited data on the productivity of such operations were available (Anon, 1969), further data were collected during studies at Tumut for this thesis (Appendix D). The average machine and labour productivity of the five winches studied is given in Table 7 (page 34 ).

Operations in which bunches of tree length logs were extracted to roadside with skidders of 97 H.P. were also studied in first thinnings at Tumut. During the studies, the breast height and merchantable small end diameters of logs extracted were measured. The predominant height of each stand was assessed and the tree volume equation prepared by the Forestry Commission of New South Wales was used to estimate log volumes.

Each operation was subdivided into elements for time study (Table 6).

TABLE 6

Elements of bunch extraction operations

| | Element |
|---|---|
| Machine time | Skidder motor working at full power, including unavoidable delays. |
| Machine idling time | Skidder motor stopped or left to idle while the operator fastens or unfastens the load, including unavoidable delays. |
| Avoidable delays | Time spent on operations other than skidding; time spent waiting for trucks to arrive, |

The data collected are given in Appendix D, times for avoidable delays having been excluded. The average machine and labour productivity of five skidders is given in Table 7 (page 34 ). It was assumed that the time spent on bunch extraction by a skidder operator was the sum of the machine and machine idling times for the skidder and an allowance for rest and meal breaks. The allowance was equal to a quarter of the total machine and machine idling time for the skidder.

Snigging with industrial tractors

In 1966, the Forestry and Timber Bureau held trials of tree length logging in first thinnings in the Bathurst plantations. An industrial tractor of 40 H.P. equipped with a safety canopy, half tracks, a double drum winch and a skid pan was used for extraction. Trees were felled toward the outrow with the tops pointing in the direction of extraction. A tree length log was cut from each tree. The tractor was reversed up the outrow and the winch rope pulled out and fastened to the tips of 6 - 8 logs by chain chokers. The logs were winched to the tractor and snigged to roadside. Time studies of snigging by three different operators on the same machine were made in several one eighth acre plots during the trials. The Bureau's data were used to determine the average machine and labour productivity as given in Table 7.

TABLE 7

Productivity in tree length extraction operations

| Method | Average machine productivity (cubic feet per machine hour) | Average labour productivity (cubic feet per man hour) |
|---|---|---|
| Tractor powered bunching winch bunching in the outrows | 166 | 129 |
| 97 H.P. Skidder extracting bunches frrom outrow to roadside | 369 | 225 |
| 40 H.P. industrial tractor snigging from stump to roadside | 252 | 81 |

# CHAPTER 4

## LOGGING FIRST THINNINGS AT BATHURST, 1972 - 1977

### Cutting productivity

The models of shortwood and tree length cutting were applied to inventory data obtained from the permanent sample plots of the Forestry Commission of New South Wales to determine the average productivity of cutting in first thinnings. Quarter acre sample plots are located at the intersections of a rectangular grid, 10 by 20 chains apart wherever the total area of a particular age class in a given plantation is 500 acres or more, and 10 by 10 chains apart otherwise.

The model of shortwood cutting (page 22 ) was used to estimate the mean cutting time per tree for each sample plot first thinned in the years 1965 - 1970. The frequency distribution of mean basal area per removed tree for the sample plots (Figure 2) showed that 24 per cent of the sample plot material fell outside the range covered in the cutting study at Sunny Corner (see Appendix B) so that some extrapolation from the model of shortwood cutting was necessary. The mean cutting time per tree estimated for each sample plot was multiplied by the number of trees removed and by the inverse of the sampling intensity. The results were all added together to determine

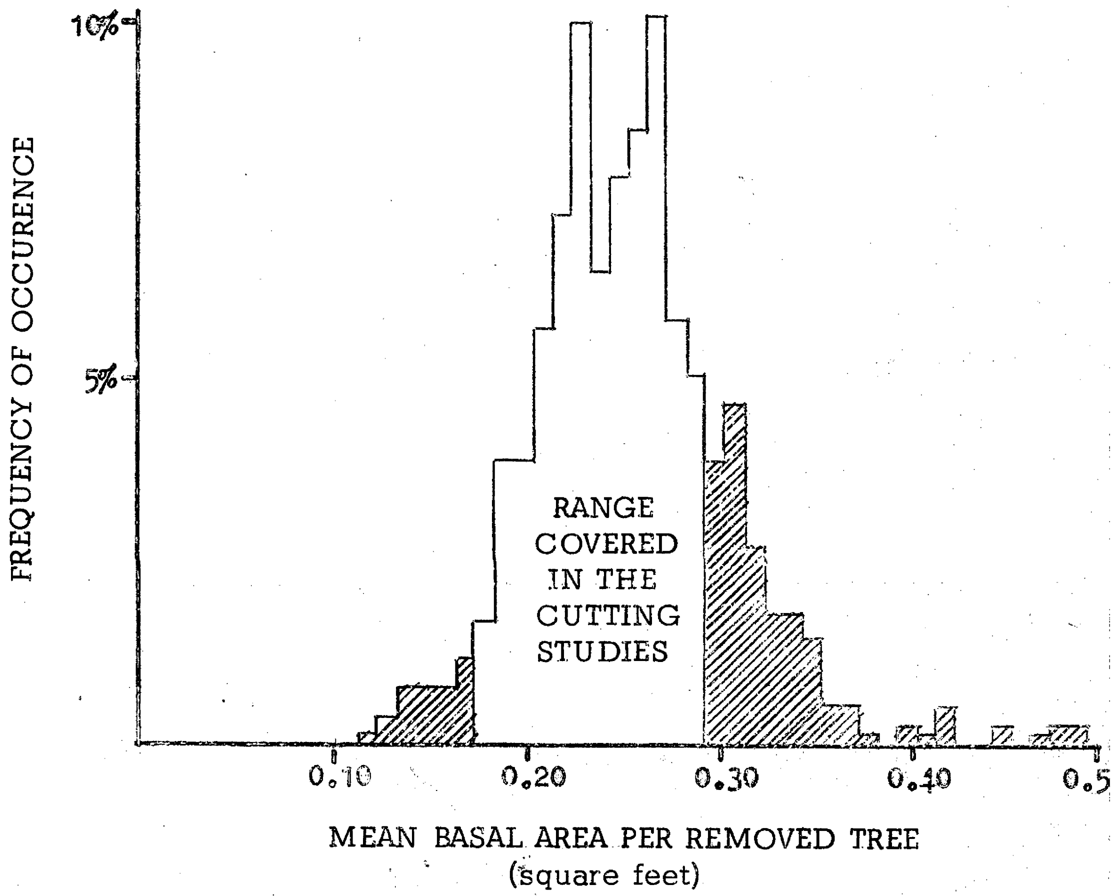


FIGURE 2

DISTRIBUTION OF MEAN BASAL AREA PER REMOVED TREE. SAMPLE PLOTS IN THE BATHURST PLANTATIONS FIRST THINNED IN 1965-1970 the working time in man hours required for cutting first thinnings in the years 1965 - 1970. Estimates of the merchantable volumes removed from first thinnings in the years 1965 - 1970 (Appendix E) were also obtained from the Forestry Commission. The total volume removed was divided by the estimated cutting time to determine the average productivity (volume output per man hour) for shortwood cutting at Bathurst. The calculations were repeated for the simulation model of tree length cutting (page 25).

The average productivity of shortwood cutting was 39 cubic feet per man hour. If tree length cutting had been used and logs left at stump for subsequent extraction, average productivity (determined by simulation) would have been 65 cubic feet per man hour. If tree length cutting had been used and logs bunched in the outrows for subsequent extraction, average productivity would have been 43 cubic feet per man hour, assuming the productivity of bunching shown in Table 7 (page 34).*

Table 8 shows the mean basal area per removed tree for all sample plots first thinned in a particular plantation in a given year from 1965 to 1970. There was little variation between plantations or from year to year. It has been assumed that thinning schedules will not be changed in the near future and that the mean basal area per removed tree will remain constant and have no effect on average cutting productivity in the years 1972 - 1977.

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*These values of average cutting productivity to the shortwood and tree length methods differ from some published previously (pages 14-16). The discrepancies are probably due to the different samples of cutters in each study. Also, previous studies may not have been made in stands which were typical for the Bathurst plantations as a whole.

TABLE 8

The mean basal area of trees removed from sample plots in the Bathurst plantations first thinned in the years 1965 - 1970 (in square feet per removed tree)

| Plantation | Year of thinning | | | | | |
|---|---|---|---|---|---|---|
| | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 |
| Glenwood | | | 0.26 | | | |
| Canobolas | 0.26 | 0.21 | 0.23 | 0.24 | 0.24 | 0.27 |
| Vulcan | | | | 0.25 | | 0.31 |
| Gurnang | 0.24 | 0.24 | 0.23 | 0.24 | 0.22 | 0.25 |
| Jenolan | 0.25 | 0.27 | 0.28 | 0.26 | 0.25 | 0.28 |
| Sunny Corner | 0.24 | 0.22 | 0.25 | 0.27 | 0.26 | 0.25 |

Wood supplies and the organization of logging

Certain assumptions were made about the organization of logging operations in the Bathurst plantations during the years 1972 - 1977 inclusive. The plantations form three geographically distinct groups shown in Figure 3. Glenwood and Canobolas plantations are situated 37 miles west of Bathurst; Vulcan, Gurnang and Jenolan are 35 miles south east, and Sunny Corner is 17 miles east. To minimize the cost of transporting men to and from work and of moving operations between felling coupes, it has been assumed that where wood supplies are adequate, logging operations would be organized separately for each group of plantations.

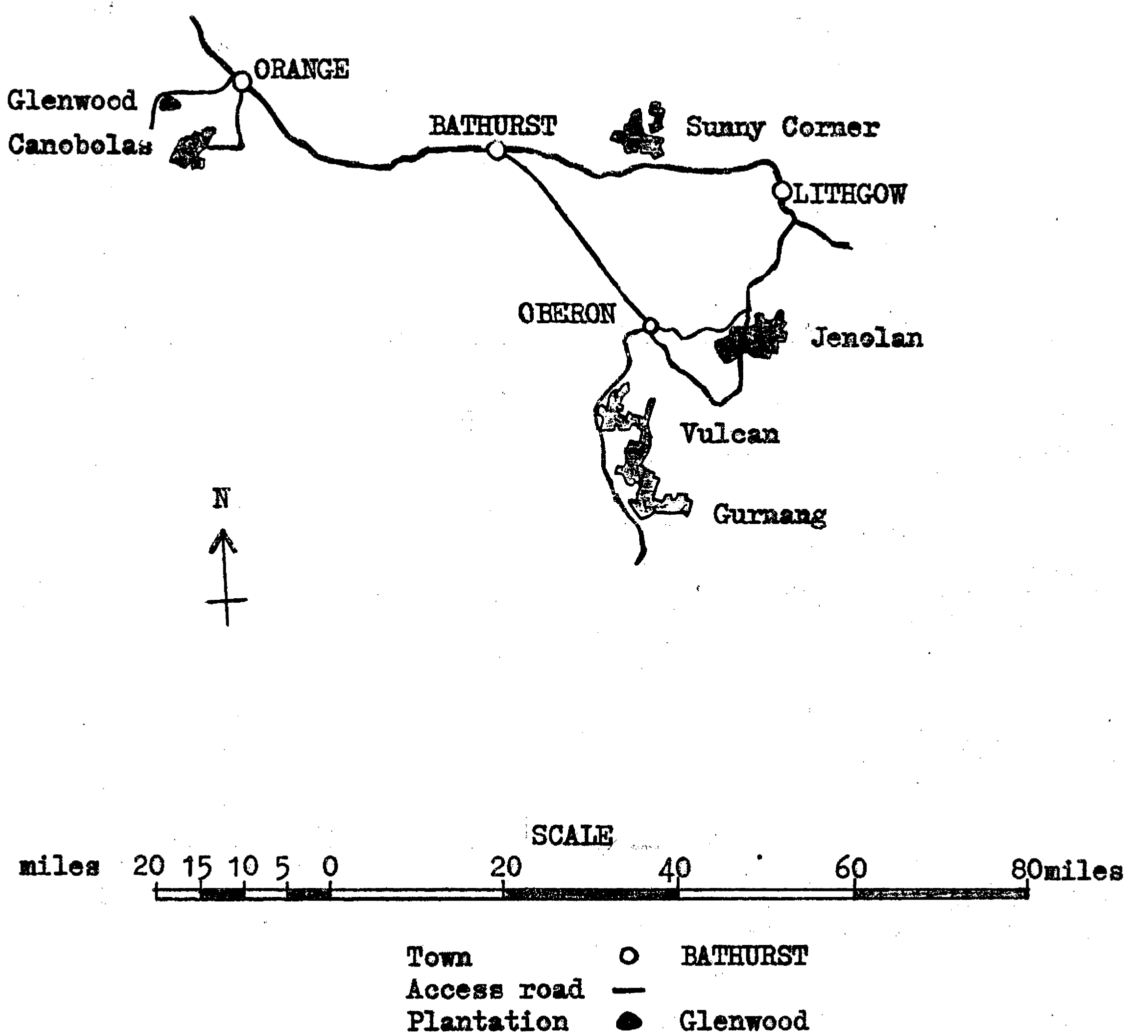


FIGURE 3

THE PLANTATIONS NEAR BATHURST, NEW SOUTH WALES
(from a map published by the Forestry Commission of New South Wales).

First thinnings produce pulpwood and are distinct from third and later thinnings which produce sawlogs. Future second thinnings may produce only pulpwood but it is more likely they will produce both pulpwood and sawlogs and require special logging operations. In forecasting plant and labour requirements for the Bathurst plantations, it may be assumed that logging operations in first thinnings will be distinct from those in later thinnings.

Data on expected yields from first thinnings in the years 1972 - 1977 were obtained from the Forestry Commission (Appendix E). Expected yields for each plantation group are shown in Table 9, with the actual yields in 1970 for comparison.

TABLE 9

Yields from first thinnings
(in thousands of cubic feet)

| Plantations | Year of thinning | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1970 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
| Glenwood Canobolas | 421 | 747 | 655 | 769 | 509 | 621 | 636 |
| Vulcan Gurnang Jenolan | 907 | 963 | 861 | 1063 | 579 | 1076 | 869 |
| Sunny Corner | 531 | 395 | 530 | 403 | 382 | 615 | 594 |
| Totals | 1859 | 2105 | 2046 | 2235 | 1470 | 2312 | 2099 |

The yield from Glenwood and Canobolas plantations in 1972 will be greater than the yield in 1970. Yields from Vulcan, Gurnang and Jenolan will be about the same in 1972 as they were in 1970 but the yield from Sunny Corner will be somewhat less. The annual yields from each of the plantation groups will remain fairly steady throughout the years 1972 - 1977 except for a marked drop in 1975. If wood supplies remain steady, no great changes in the scale of logging operations are likely, but possible effects of reduced wood supplies in 1975 on labour requirements for cutting will be shown later.

To provide stable conditions for plant utilisation and labour employment in the Bathurst plantations, the proposed thinning schedule should be adjusted to increase the yield for 1975. Before such action could be taken, however, the total commitments on wood supply from the plantations would have to be considered.

Plant and labour requirements

The expected yields from first thinnings were divided by the estimates of average cutting productivity to forecast the working time required. The required working time, expressed in man hours, was divided by the ordinary working hours specified in the Timber Workers Consolidated Award (pages 82 and 83) and the result taken up to the nearest whole number to estimate the number of cutters required. Numbers of cutters required are given in Table 10 and may be regarded as the minimum requirements because individual cutters would lose working time through sickness, injuries and wet weather; some cutters would not wish to work as many as forty hours each week and others would be employed on a casual basis.

TABLE 10

Minimum numbers of shortwood cutters required

| Plantation | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
| Glenwood Canobolas | 10 | 9 | 10 | 7 | 9 | 9 |
| Vulcan Gurnang Jenolan | 13 | 12 | 14 | 8 | 14 | 12 |
| Sunny Corner | 6 | 7 | 6 | 5 | 8 | 8 |

The number of cutters required for shortwood logging will remain roughly the same from 1972 to 1977 except in 1975. The normal requirements will be 9 cutters for Glenwood and Canobolas plantations; 12 for Vulcan, Gurnang and Jenolan plantations and 7 for Sunny Corner plantation. In 1975 the number of cutters required will drop and about 10 cutters could be laid off at the end of 1974 to return early in 1976. Recruitment could be difficult if a general shortage of labour were to occur in 1976. However, the proposed schedule of first thinnings could be adjusted to ensure steady employment for experienced cutters.

Table 11 gives average annual cutter requirements for three alternative logging methods for the Bathurst plantations; i.e. the shortwood method, the tree length method where logs are snigged directly from stump to roadside, and the tree length method where cutters are required to bunch their logs.

TABLE 11

Numbers of cutters required for alternative logging methods

| Plantation | Shortwood cutting | Tree length cutting only | Tree length cutting and bunching |
|---|---|---|---|
| Glenwood Canobolas | 9 | 6 | 8 |
| Vulcan Gurnang Jenolan | 12 | 7 | 11 |
| Sunny Corner | 7 | 4 | 6 |

Fewer cutters would be required for either tree length logging method than for the shortwood method. The reduction achieved would be only slight however, if the cutters in tree length operations were also required to bunch their logs.

Numbers of machines and operators required for each possible method of extraction were determined, assuming no machine would be available for more than 1600 machine hours per annum and no operator would work more than the ordinary hours specified in the

Timber Workers Consolidated Award. It was also assumed that each machine would have only one operator and that extraction operations would not be delayed by hauling operations. Estimated plant and labour requirements for extraction are given in Table 12.

TABLE 12

Numbers of machines required for extraction

| Plantations | Forwarders to extract shortwood billets | Skidders to extract shortwood billets | Tractors to bunch tree length logs | Skidders to extract bunched tree length logs | Industrial tractors to extract tree length logs |
|---|---|---|---|---|---|
| Glenwood<br>Canobolas | 2 | 1 | 8 | 2 | 5 |
| Vulcan<br>Gurnang<br>Jenolan | 2 | 1 | 11 | 3 | 6 |
| Sunny Corner | 1 | 1 | 6 | 2 | 4 |

## Logging costs

Unit costs for wood delivered to roadside were calculated for each alternative logging method using the plant and labour requirements shown in Table 13 (page 45). Hourly wage rates for cutters and machine operators were obtained from the Timber Workers Consolidated Award, assuming payment by results. Hourly costs of machinery were based on data in Appendix F. The costs of alternative shortwood and tree length logging methods are given in Table 14 (page 45). Fewer cutters would be required for tree length logging than shortwood

TABLE 13

Plant, labour and capital requirements for logging first thinnings in the Bathurst plantations

| Item | Shortwood cutting forwarder extraction | Shortwood cutting skidder extraction | Tree length cutting bunching & skidding | Tree length cutting industrial tractor snigging |
|---|---|---|---|---|
| Number of cutters | 28 | 28 | 25 | 17 |
| Number of operators | 5 | 3 | 7 | 15 |
| Total number of men | 33 | 31 | 32 | 32 |
| Average capital investment in plant | $47,000 | $45,200 | $152,200 | $65,100 |

TABLE 14

Costs per 100 cubic feet for shortwood and tree length logging operations

| Item | Shortwood cutting forwarder extraction | Shortwood cutting skidder extraction | Tree length cutting bunching & skidding | Tree length cutting industrial tractor snigging |
|---|---|---|---|---|
| Cost of cutting | $4.36 | $4.36 | $2.62 | $2.62 |
| Cost of bunching | | | $2.50 | |
| Cost of extraction to roadside | $2.58 | $1.30 | $3.54 | $4.06 |
| Total Cost | $6.94 | $5.66 | $8.66 | $6.68 |

logging. Tree length cutting would be much cheaper than shortwood cutting, provided tree length cutters were not required to bunch logs in the outrow. Tree length extraction, however, would require more men than shortwood extraction, would be dearer and would require a higher level of capital investment in mechanical plant.

Of the alternative methods considered for shortwood extraction a 97 H.P. skidder equipped with a loading boom, would be cheaper than a 42 H.P. forwarder. If a majority of shortwood cutters, however, were to use the same cutting method as Cutter 3 at Sunny Corner (see page 17 ) the cost of preparing stacks containing 20 cubic feet for forwarder extraction should be less than the cost of preparing stacks containing 60 cubic feet for skidder extraction. It is unlikely any reduction in cutting costs favouring shortwood logging with forwarders would compensate for the difference between forwarder and skidder extraction costs.

Tree length logging with specially equipped industrial tractors snigging logs directly from stump to roadside would be slightly cheaper than shortwood logging with forwarders but dearer than shortwood logging with skidders. Better performance and higher productivity might be expected of tractor operators paid by results than operators in field trials such as those from which the data on industrial tractor snigging came. Tree length extraction with bunching tractors and skidders would be the dearest of all the methods considered.

Efficient shortwood operations with skidders of 97 H.P. equipped with loading booms would be the most economical method for logging first thinnings at Bathurst in terms of both total labour requirements and cost per unit volume for wood delivered to roadside. A change to tree length logging might, however, be considered for other reasons such as safety. Shortwood cutters must lift and carry billets weighing up to 300 pounds each. This activity is strenuous and involves risk of muscular injury. Shortwood cutters who attempt to trim branch stubs on billets while carrying them frequently suffer axe cuts to their forearms. Such activities are eliminated in tree length cutting, which should provide safer working conditions. A change to tree length logging might also be considered if it could allow more economical handling at the mill yard.

Although the shortwood logging method appears to be the more economical for first thinnings at Bathurst, it may not be so elsewhere. Shortwood logging could be dearer if the billet length were shorter than eight feet because more billets would be crosscut and stacked from a given volume of wood and the productivity of shortwood extraction may be limited by the sectional area of the load carried. Kerruish (1967) believes the unit cost of tree length logging would decrease as the mean volume per removed tree increased. If this were so, tree length logging operations might be more economical than shortwood ones in plantations with higher growth rates than at Bathurst, or where a significant proportion of first thinnings were delayed or where the same logging method must be used for both first and second thinnings.

# PART II

# STUDIES OF CUTTING PRODUCTIVITY

# CHAPTER 5

## DETAILED TIME STUDIES OF SAWLOG CUTTING

Most sawlogs removed from Australian pine plantations come from third or later thinnings or clear fellings, the cutting operations being organized separately from those in first thinnings. No studies of sawlog cutting had been made in Australia before the studies for this part of this thesis were arranged but earlier studies of cutting in first thinnings provided an introduction to some of the problems involved in Detailed time study. Since data collected by Detailed time study could also provide observations for Gross Data time study, the former technique was used for the fieldwork. The studies were arranged to cover as wide a range of tree dimensions and stocking conditions as possible but to interfere with cutting operations as little as possible. The field procedure adopted allowed the studies to fit in with the work methods used by the cutters. Time studies were made wherever cutters happened to be working at the time, provided the site was free from obstructions such as dense natural regeneration or blackberry bushes and the ground slope was less than twenty degrees. The restrictions were imposed to confine sampling to the more important types of work site in pine plantations.

Sawlog cutting operations in the coniferous plantations in New South Wales and the Australian Capital Territory are confined to stands of prewar planted radiata pine. In New South Wales, such stands are located near Bathurst, Tumut and Bombala. They are now thinned every three to five years but previous thinnings in some stands may have been irregular.

## Work methods for sawlog cutting

Most sawlog cutters work alone but sometimes two or three men work together as a team. Five to ten trees at a time are felled and successively trimmed, measured and docked. Felling is done with chain saws. Trimming involves cutting off all accessible branches with an axe as close to the stem as possible. Measuring involves selecting the sawlogs to be cut from each felled tree in accordance with sawmill specifications. Each sawlog length is measured with a light measuring stick and marked with an axe nick or lumber crayon. Trees are then docked (i.e. cross-cut) into log lengths with a chain saw. Logs may contain two or more sawlog lengths which are subsequently docked at the sawmill. Many cutters inspect their logs after extraction, removing any remaining branch stubs because sawmillers may refuse logs if branch stubs are left. This work is called "spiking".

Cutters need rest periods from time to time to recover from fatigue. Much of this rest is taken during meal breaks which cutters take as they please. In time studies made for this thesis, time required for rest was indistinguishable from time spent on actual meal breaks. Each cutter or team of cutters was studied for at least one full working day to ensure rest and meal breaks were adequately sampled.

From time to time cutting work is interrupted. Such interruptions are regarded as "avoidable delays" in work study if they could be overcome by improved working technique or better organization; otherwise they are regarded as "unavoidable delays". In time studies for this thesis, delays resulting from a variety of causes were regarded as unavoidable; for example if felling was delayed when a tree, blown away from the intended felling direction, became lodged in the crown of a standing tree. Other unavoidable delays are noted in Appendix A. Whenever cutters assisted with or were hindered by operations other than cutting or wasted time for no apparent reason, the resulting delay was regarded as avoidable.

## Field procedures for the studies

The cutting operation was sub-divided into elements for Detailed time study. These are given in Table 15. Most of the elements are self explanatory but detailed definitions are given in Appendix A. Since cutters working as a team performed different elements concurrently, each cutter was studied individually.

TABLE 15

Elements of sawlog cutting operations

| Sub-operation | Element | Symbol |
|---|---|---|
| Felling | Collect tools | 1 |
| | Walk to tree | 2 |
| | Inspect and prepare to fell | 3 |
| | Saw | 4 |
| | Remove splinters from butt of felled tree | 5 |
| Trimming | Collect tools | 6 |
| | Walk to tree | 7 |
| | Trim branches | 8 |
| Measuring | Collect tools | 9 |
| | Walk to tree | 10 |
| | Measure log lengths | 11 |
| Docking | Collect tools | 12 |
| | Walk to log | 13 |
| | Crosscut | 14 |
| Spiking | Spike | 15 |
| Miscellaneous | Clear slash from outrow | 16 |
| | Chain saw maintenance | 17 |
| | Organizational delays | 18 |
| | Rest and meal breaks | 19 |

The time study commenced at the cutter's normal hour of starting and generally finished when between 50 and 80 trees had been cut. This sampling unit ensured each operation was studied for at least one full working day, including all normal meal breaks. The sequence of elements performed by the cutter was observed and the time taken to perform each element was measured to the nearest one hundredth of a minute with a stopwatch having a split, fly-back hand. As each tree was felled, an adhesive label bearing an identity number was attached to its butt end.

Two measurers accompanied the time study officer. Whilst each felled tree was trimmed, one measurer measured its overbark diameter at the butt, the breast height point and at ten feet intervals along the stem to the limit of trimming. Diameters were measured to the nearest tenth of an inch with calipers. The bark thickness at each of these points was also measured to the nearest tenth of an inch from a single insertion of a bark gauge. When sawlogs were docked, their lengths were measured to the nearest foot.

The second measurer measured a systematic sample of the branch knots resulting from trimming. Starting from the butt of each tree, every fourth whorl of branches on the merchantable stem was sampled. The diameter of each branch knot on the topside of the stem at the sample whorl was measured to the nearest tenth of an inch perpendicular to the axis of the tree. The branch measurements were used for special studies of trimming work by Detailed time study.

At the conclusion of each study a rectangular plot, usually 120 by 180 feet, was laid out in the middle of the area from which trees had been removed. The breast height diameter of each standing tree in the plot was measured to estimate the residual basal area and the number of fresh stumps was counted to assess the number of trees removed per acre. The heights of what seemed to be the five tallest trees standing in or close to the plot were measured and the mean height of the three tallest of these five was used as an estimate of the predominant height in the plot. The ground slope was also measured.

The merchantable small end section area (hereafter called the small end area) of each tree felled in the study was estimated by interpolation from the measurements made along its stem, assuming linear taper between each adjacent pair of measurement points. The underbark merchantable volume (hereafter called the volume) of each felled tree was estimated from its breast height diameter, small end diameter and the predominant height of the stand using a tree volume equation for radiata pine prepared by the Forestry Commission of New South Wales:

$$V = (2.92359 + 0.00733\,J^2 - 0.05663\,E + 0.001816\,J^2 E) \times \left(1.0 + 0.2488\,\frac{K}{J} - 1.0335\,\frac{K^2}{J^2}\right)$$

where V denotes volume in cubic feet
J denotes breast height diameter in inches
K denotes small end diameter in inches
E denotes predominant height in feet.

Volumes estimated from the tree volume equation were used to express the output from cutting operations during the studies. Another estimate of the underbark merchantable volume of each felled tree was made from the measurements at points along its stem using Smalian's formula. These measured volumes were used to check the precision of the tree volume equation.*

*Both the tree volume equation and the field measurements only provide estimates of actual merchantable volume; however, the field measurements probably give a more precise estimate than the tree volume equation. The tree volume equation was used in constructing the model of cutting productivity because it relates volume /cont.

The total time spent on each element of the cutting operation in each study plot was determined. Delays were classified as avoidable or unavoidable and the time for any unavoidable delay associated with a specific element was added to the time for that element. The remaining unavoidable delays had generally been caused by supervisory activities and were grouped together as "organizational delays". Avoidable delays were disregarded in the time study analyses because they consisted of time spent on operations other than cutting.

Where cutters had helped to extract logs to roadside, the time spent on rest and meal breaks during cutting alone R′ was estimated from the time spent on rest and meal breaks during cutting and extraction R, the time spent on actual cutting C and the time spent on actual extraction E. It was assumed that cutting and extraction were equally strenuous and that

$$R' = R \times \frac{C}{C+E}$$

The total time for each element in each study plot was divided by the number of trees felled in the plot to determine the mean element time per tree. The stand measurements and time study data are given in Appendices G and H.

## Results by Detailed time study

The effects of stand variables on the mean time per tree for each element of cutting were studied by regression analysis. Stand

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*To other stand variables such as breast height diameter. In using the cutting productivity model for predictive purposes the stand characteristics required to determine mean volume per removed tree could be obtained from sample plot records. Otherwise it would be necessary to fell sample trees and measure them to determine their volumes.

variables which might have affected each element were chosen initially from those in Table 16, using the results of previous studies and common sense for guidance.

TABLE 16

Stand variables

| Stand variable | Symbol |
|---|---|
| Mean basal area per removed tree (in square feet) | A |
| Diameter equivalent to A (in inches) | B |
| Mean small end area (in square feet) | C |
| Diameter equivalent to C (in inches) | D |
| Predominant height (in feet) | E |
| Number of trees removed per acre | F |
| Number of trees per acre standing before thinning | G |
| Mean length of logs cut (in feet) | H |
| Ground slope (in degrees) | I |

The constant and regression coefficients of the equation finally chosen for each element are given in Table 17. Each regression coefficient was significant at the 95 per cent level of probability.

Symbols used in Table 17 for elements and stand variables are interpreted in Tables 15 (page 51) and 16 respectively. Two results are given for element 5; that marked * applies where A $\leqslant$ 1 square foot and is based on eight observations; that marked ' applies where A $>$ 1 square foot and is based on sixteen observations. All other results are based on twenty four observations.

TABLE 17

Results of Detailed time studies of sawlog cutting

| Element Symbol | Constant | Coefficients of significant stand variables A | B | D | E | H | F | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.14 | | | | | | | |
| 2 | 0.07 | | | | | | 1.61<br>(±0.38) | 0.67 |
| 3 | 0.02 | 0.14<br>(±0.05) | | | | | | 0.52 |
| 4 | -0.29 | 0.82<br>(±0.14) | | | | | | 0.79 |
| 5* | 0.00 | | | | | | | |
| 5' | -0.13 | 0.13<br>(±0.04) | | | | | | 0.68 |
| 6 | 0.15 | | | | | | | |
| 7 | 0.09 | | | | | | 1.22<br>(±0.57) | 0.41 |
| 8 | -0.21 | | 0.62<br>(±0.06) | -0.70<br>(±0.15) | | | | 0.91 |
| 9 | 0.14 | | | | | | | |
| 10 | 0.24 | | | | | | | |
| 11 | 0.12 | 0.55<br>(±0.15) | | | | | | 0.63 |
| 12 | 0.19 | | | | | | | |
| 13 | -0.47 | | | | 0.0094<br>(+0.0045) | | | 0.41 |
| 14 | 0.49 | 1.07<br>(±0.27) | | | | -0.058<br>(±0.024) | | 0.69 |
| 15 | 0.10 | | | | | | | |
| 16 | 0.29 | | | | | | | |
| 17 | -0.15 | 0.56<br>(±0.17) | | | | | | 0.57 |
| 18 | 0.32 | | | | | | | |
| 19 | -0.11 | 2.60<br>(±1.12) | | | | | | 0.45 |

Discussion of the results for each element

Collect tools for felling, trimming, measuring or docking:

Common sense suggests the work methods of individual cutters affected time spent on these elements (1, 6, 9, and 12) more than any stand characteristic. Mean times per tree for collecting tools were calculated separately for each sub-operation because different tools were required. The mean times per tree for collecting tools for felling, trimming and measuring were about equal but less than the mean times per tree for collecting tools for docking.

Walk to tree for felling, trimming or measuring:

During felling, cutters walked from the stump of each newly felled tree to the next tree to be felled. In order to avoid obstacles and search for other trees marked for felling, they could not follow the shortest path from tree to tree exactly but it is reasonable to assume they tried to do so. The element "walk to tree" was repeated during trimming and measuring. Conditions for walking differed in each instance. Logging slash increased as cutting work progressed and whilst a chain saw weighing anything from 15 to 30 pounds was carried for felling, only light hand tools such as a 3 pound axe were required for trimming and measuring. Furthermore, cutters could so arrange a group of trees by careful felling that the walking distance between them would be reduced during subsequent sub - operations.

Theoretical results published by Matern (1960) suggested that if removed trees were spaced at the intersection of a network of squares or equilateral triangles or in a square network with one randomly located tree in each square, the average distance between adjacent removed trees along the shortest path passing through them all would be the unit of length which, when squared, gives the average unit area per removed tree. Assuming walking time is proportional to the distance walked on each occasion and the shortest path between removed trees is followed, mean walking time per tree should be inversely proportional to the square root of the number of trees removed per acre.

The derived regression model was significant for the elements "walk to tree" for felling (2) and "walk to tree" for trimming (7) but not "walk to tree" for measuring (10).

Inspect and prepare to fell, and Saw:

Both these elements (3 and 4) were significantly affected by mean basal area per removed tree, corroborating results obtained by Samset et al (1969). Neither element was significantly affected by the number of trees per acre before thinning, suggesting cutters were sufficiently skilled in directional felling to avoid lodging trees.

Remove splinters from butt of felled tree:

Appreciable butt splinters may form if a tree falls before it has been adequately sawn through, i.e. cut so that only a narrow hinge up to one inch wide remains uncut between the back and fore cuts. Butt splintering is most likely to occur when a large tree is felled in its direction of lean. The stresses created in felling such a tree are considerable and very precise felling techniques are required to avoid butt splintering.

It was not necessary to remove splinters from the butt of every tree felled for the study; often they were absent or negligible. The mean time per tree for removing splinters (element 5) was plotted against the mean basal area per removed tree (Figure 4). It was seen that the mean time per tree was negligible when the mean basal area per removed tree was less than 1 square foot, suggesting butt splinters were rare occurrences in such stands. As the mean basal area per removed tree increased above 1 square foot, the mean time per tree increased proportionately. A regression of mean time per tree for the element on mean basal area per removed tree was calculated from data on sample plots in which the latter was greater than 1 square foot.

Trim branches:

Special studies of trimming (Appendix I) showed mean time per tree for this element (8) was related to the mean value per tree of the aggregated diameters of knots resulting from trimmed branches. Another study showed rates of trimming dead and live branches of radiata pine were the same. Studies by Jacobs (1938)

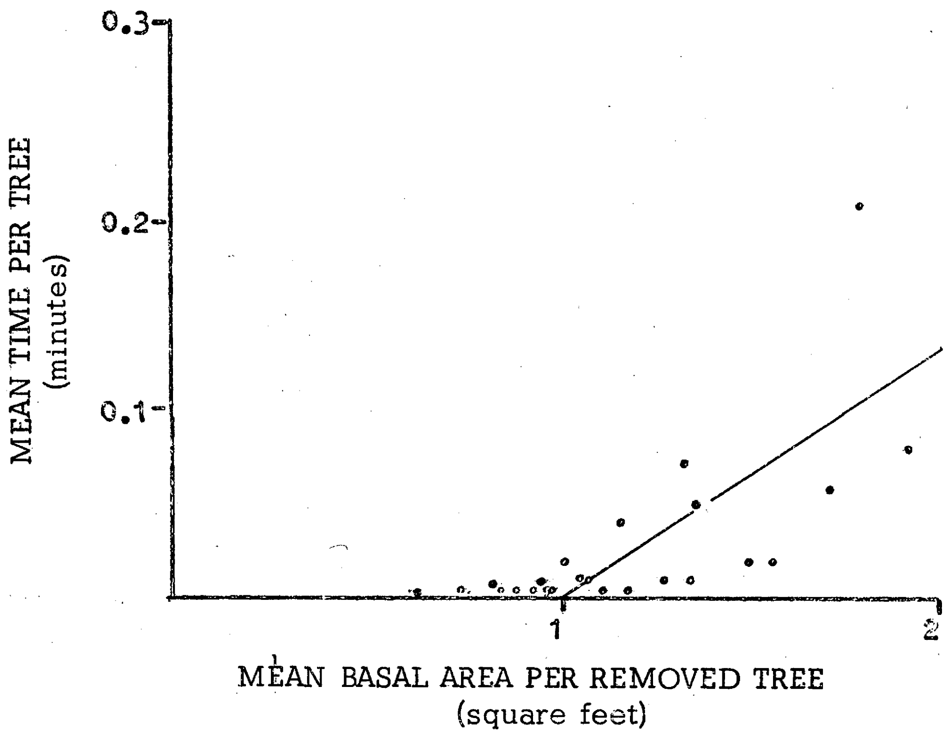



FIGURE 4

TIME SPENT REMOVING SPLINTERS FROM BUTTS OF FELLED TREES and Cromer and Pawsey (1957) indicated the thickness of branches in radiata pine could be related to breast height diameter and taper.

It was found that the diameters equivalent to mean basal area per removed tree and mean small end area significantly affected the mean time per tree for trimming branches. Small end diameter and height provides a measure of taper for a given breast height diameter. The diameter equivalent to mean small end area had a negative regression coefficient, indicating increased taper of the merchantable stem resulted in increased trimming time. The rate of taper affects the position of the lower boundary of the green crown but this would not affect trimming times since dead branches of radiata pine are very persistent and rates of trimming dead and live branches do not differ. However, branch frequency (i.e. number per unit length) increases along the stem from butt to tip. The greater the taper of the merchantable stem, the more the branches to be trimmed, and the longer the trimming time.

Measure log lengths:

This element (11) involved walking along each felled tree in turn, measuring successive log lengths from the butt and marking them off. It appeared likely that the mean time per tree for the element depended on mean merchantable length per removed tree. Regressions of the mean time per tree for the element on two stand variables related to mean merchantable length were tested. Both regressions were significant but the regression on one of the stand variables, mean basal area per removed tree, was more highly significant than the regression on the other, predominant height. Cutters may have spent longer measuring trees of greater basal area because measuring each log length also involved grading. Sawlogs are specified by length and grade, grades being largely based on small end diameter with bigger diameters having better grades. The greater the mean basal area per removed tree, the greater the number of alternative grades which could be cut from each individual tree, and the greater the amount of grading work involved in measuring.

Walk to log:

In docking, cutters usually walked along each felled tree in turn making crosscuts where necessary. The mean time per tree for this element (13) could have depended on mean merchantable length per removed tree and was found to be significantly affected by predominant height, a stand variable related to mean merchantable length per removed tree.

Crosscut:

Common sense suggested mean time per tree for this element (14) was likely to depend on mean basal area, mean taper per removed tree and the mean length of logs cut. It was found the first and last of these variables had significant effects but mean small end area, a measure of taper for trees with a given mean basal area, had no significant effect.

Spike, and Clear slash from outrow:

Time spent on these elements (15 and 16) seemed to have been affected by felling, trimming and snigging methods rather than stand characteristics. Thus the mean time per tree for each element was calculated and used.

Chain saw maintenance:

Common sense suggested this element (17) was probably related to the amount of sawing and crosscutting done and it was found that mean basal area per removed tree, which significantly affected mean times per tree for the elements "saw" and "crosscut", affected the mean time per tree for chain saw maintenance as well. No regressions on other stand characteristics were attempted for this element.

Organizational delays:

Common sense suggested the supervision and organization of logging operations (element 18) was generally carried out independently of differences between stands, hence no regressions on stand characteristics were attempted.

Rest and meal breaks:

Mean basal area per removed tree significantly affected the mean time per tree for rest and meal breaks (element 19). This was logical because mean times per tree for the elements "saw" and "crosscut" were significantly affected by mean basal area per removed tree and the mean time per tree for the element "trim branches" was significantly affected by the diameter equivalent to mean basal area per removed tree, these being three of the most strenuous and time consuming elements of cutting.

The effect of obstructions:

Results presented above were obtained in stands from which obstructions such as dense undergrowth, natural regeneration or hardwood debris were largely absent. The presence of any of these obstructions could hinder walking through a stand and tool collection. Natural regeneration and undergrowth taller than the height of a man could also hinder the recognition of trees marked for removal and limit the choice of felling direction. Obstructions around the base of a tree would have to be cut away before felling could commence.

Obstructions could increase the time spent on various elements of cutting or increase fatigue in cutters, necessitating longer rest breaks. Research is needed in this regard because prewar plantations will become more open with continued heavy thinning, and dense undergrowth or natural regeneration could develop.

The effect of ground slope:

In selecting sample plots, ground slope had been limited to a maximum of twenty degrees. Samset et al (1969) found times per tree for cutting Norway spruce sawlogs increased with ground slope. From Samset's results a decrease in cutting productivity of about 8 per cent would be expected on a twenty degree slope compared with flat ground. A greater decrease would be expected if tree length logs were cut. Whiteley (1971) measured the productivity of a team of two men cutting tree length logs of radiata pine in delayed first thinnings on five different slopes. Cutting productivity on a sixteen degree slope was 30 per cent less than that on flat ground but the trend of decreasing productivity on twenty-three, twenty-nine and thirty-six degree slopes suggested productivity on the sixteen degree slope was abnormally low and should have been only 10 per cent less than that on flat ground.

These results suggest ground slope may affect cutting productivity but no significant effects were found on slopes limited to a maximum of twenty degrees.

## Estimating working time for cutting

The working time required for cutting was determined by aggregating results of the Detailed time studies. All the constants and coefficients in Table 17 (page 56 ), expressing effects of stand variables on elements of sawlog cutting, were combined to obtain an equation for the aggregate effects of stand variables on mean cutting time per tree. The equation was:

$$T = 1.13 + 5.74\,A + 0.62\,B - 0.70\,D + 0.0094\,E - 0.058\,H + 2.83\,\frac{1}{F} - 0.13\,L + 0.13\,A\,L$$

where T denotes mean cutting time per tree in minutes and all other symbols except L are defined in Table 16 (page 55 ); L takes the value 0 when A is less than or equal to 1 square foot and the value 1 otherwise. This equation could be used to estimate working time in man minutes required for sawlog cutting operations in any stand whose characteristics lie within appropriate limits.

To obtain a measure of the precision of estimates of mean cutting time per tree from the above equation, the residual variance, $\sigma_T^2$, was calculated. The equation for mean cutting time per tree was the aggregate of several regression equations for mean element times per tree. If these elements were truly independent of one another, the variance of mean cutting time per tree would be the sum of the element variances for all elements of cutting;

$$\sigma_T^2 = \sum_{i=1}^{i=I} \sigma_i^2$$

The element time regressions obtained by Detailed time studies above were not independent, however, because each cutter had performed elements sequentially. The covariance of every pair of elements (i and j say), which were not independent of each other, had therefore to be added to the sum of the element variances giving;

$$\sigma_T^2 = \sum_{i=1}^{i=I} \sigma_i^2 + 2 \sum_{i=2}^{i=I} \sum_{j=1}^{j=i-1} \sigma_{ij}$$

The residual variances and covariances (i.e. variances and covariances remaining after the effects of stand variables on mean element times per tree had been taken into account) are given in Appendix J. The residual variance $\sigma_T^2$ of estimates of mean cutting time per tree was 9.02 squared man minutes per tree.

## Estimating output from cutting

The output from cutting operations is commonly expressed in terms of volume. Volumes of removed trees were estimated from the tree volume equation (page 53 ). The precision of such an estimate was calculated from the residual variance of the tree volume equation. Direct estimates of the variance of the tree volume equation were, however, not available. An approximation of the required variance was made for use in this thesis.

The tree volume equation had been prepared from measurements on 2087 trees obtained by felling all trees in numerous one tenth acre plots. The equation is actually the product of two separate regression equations estimated from the same data. The first regression equation expresses total tree volume as a function of two highly significant variables; the breast height diameter of the tree and the predominant height of the stand. The regression has a coefficient of determination ($R^2$) of 0.98 and a standard error of $\pm$ 5 cubic feet. The second regression equation expressed the ratio of merchantable to total volume as a function of the small end and breast height diameters of the tree. This regression has a coefficient of determination of 0.95 and a standard error of $\pm$ 0.06.

For a given small end diameter, the variance of an estimate from the tree volume equation should be

$$\sigma_V^2 = \sigma_M^2 N^2 + \sigma_N^2 M^2 + 2\sigma_{MN} MN$$

where an estimate of merchantable volume V (with variance $\sigma_V^2$) is the product of an estimate of total volume M (with variance $\sigma_M^2$) and an estimate of the ratio of merchantable to total volume N (with variance $\sigma_N^2$). The covariance $\sigma_{MN}$ of M and N should also be taken into account (see Appendix K). Standard errors for the regressions of total volume and the ratio of merchantable to total volume in the tree volume equation have been given but the covariance between those regressions has not. The covariance could only be determined from the original set of observations, which was not readily available.

Since the variance of the tree volume equation could not be determined from its source data, it was independently estimated from volumes of trees felled in the studies for this thesis. Data on all trees felled and measured were pooled and grouped into five classes, each containing approximately one fifth of the total measured volume. The volume of each tree was also estimated from the tree volume equation and subtracted from the measured volume to obtain the residual (i.e. error remaining after variations in volume attributable to variables in the tree volume equation had been into account). The mean squared residual of trees in each class was calculated. These classes, their mean measured volumes and mean squared residuals are given in Table 18.

TABLE 18

Mean squared residuals about the tree volume equation (determined from independently measured volumes)

| Range of measured volume per tree (cubic feet) | Mean measured volume per tree (cubic feet) | Mean squared residual (squared cubic feet) |
|---|---|---|
| 1.0 - 25.9 | 17.0 | 19.50 |
| 26.0 - 35.9 | 32.9 | 41.50 |
| 36.0 - 45.9 | 42.1 | 49.75 |
| 46.0 - 60.9 | 54.5 | 75.23 |
| 61.0 + | 77.1 | 182.85 |

The variance of the mean volume per tree for a sample of removed trees could not be determined from the mean squared residuals about the tree volume equation which were clearly heterogeneous (i.e. not constant).

An approximation to the true variance of the mean volume per removed tree for a sample of removed trees was made by grouping together data on trees felled and measured in each study plot. The mean squared residual about the tree volume equation was plotted against the mean volume of removed trees in each plot (Figure 5). They were found to be linearly related and the equation

$$Q = - 24.63 + 2.08 V$$

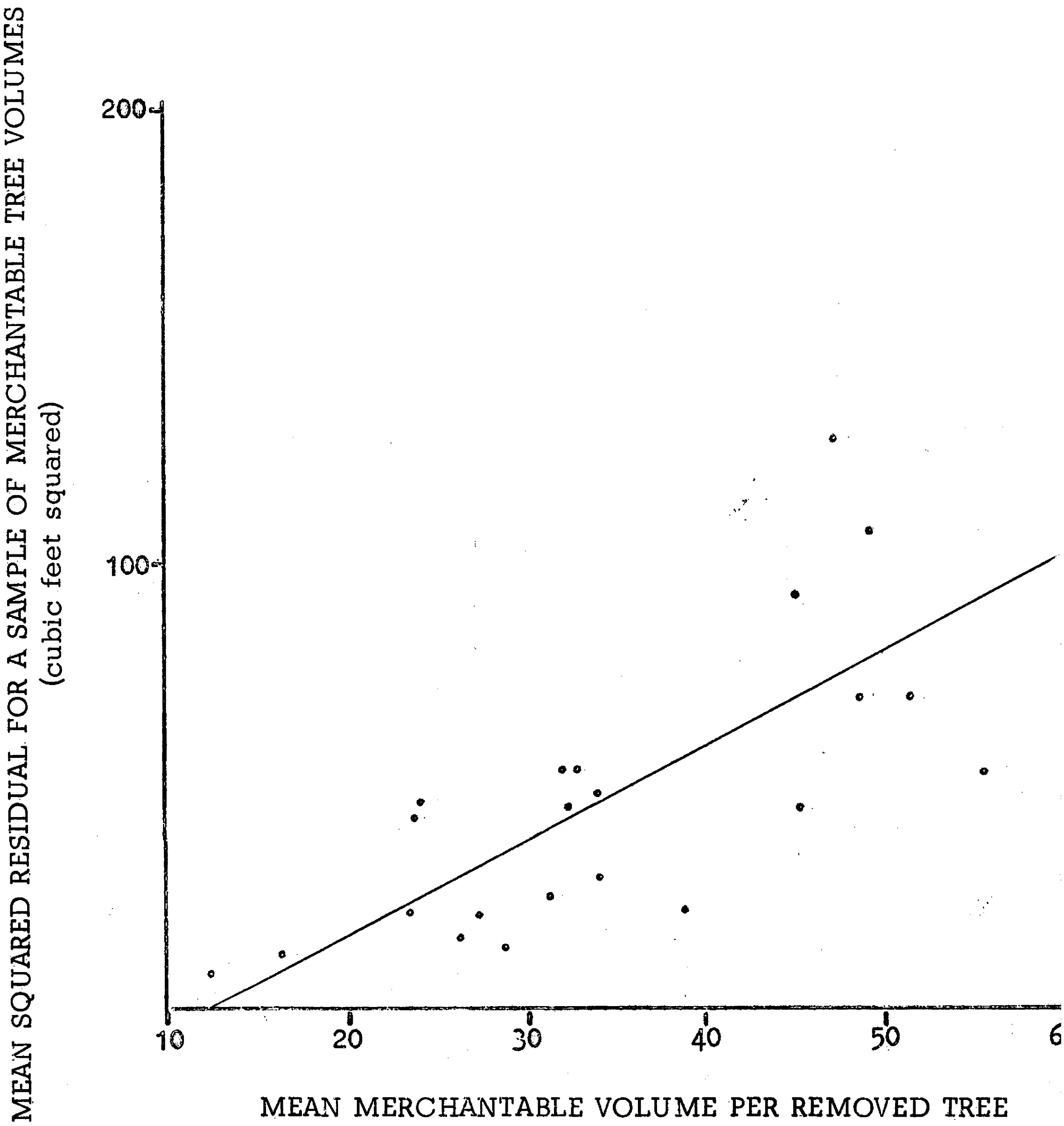
could be used to estimate the mean squared residual Q in squared cubic feet for a given mean volume per removed tree V in cubic feet. The approximate variance of the mean volume per tree for a sample of removed trees would be the value of Q obtained from the above equation divided by the number of trees in the sample.

## Estimating cutting productivity

Cutting productivity is usually expressed in terms of volume output per man hour. An estimate of cutting productivity is given by

$$P = \frac{V}{T}$$

where V is mean volume per removed tree and T is mean cutting time per tree. V can be estimated from the tree volume equation on page 53 and T from the equation for mean cutting time per tree on page 66. Since these equations were prepared from independent data sets giving estimates of V and T (with variances $\sigma_V^2$ and $\sigma_T^2$ respectively) the precision of estimates of cutting productivity can be measured by the variance $\sigma_P^2$ of the productivity quotient:




MEAN MERCHANTABLE VOLUME PER REMOVED TREE
FROM THE RECOMMENDED TREE VOLUME EQUATION
(cubic feet)

FIGURE 5

ESTIMATED RESIDUAL VARIANCE
ABOUT THE TREE VOLUME EQUATION PREPARED BY
THE FORESTRY COMMISSION OF NEW SOUTH WALES

$$\sigma_P^2 = \frac{\sigma_V^2 \; T^2 + \sigma_T^2 \; V^2}{T^4}$$

(see Appendix K). From estimates of $\sigma_V^2$ and $\sigma_T^2$ obtained, the variance of cutting productivity was calculated to be

$$\sigma_P^2 = \frac{3600 \left[ \left[ \frac{2.08 \; V - 24.63}{N} \right] T^2 + 9.02 \; V^2 \right]}{T^4}$$

where N is the number of trees sampled to estimate V.

The estimated cutting productivity and its variance were calculated for each study plot (Table 19).

TABLE 19

Productivity and its variance estimated by Detailed time study

| Study plot | Estimated productivity (cubic feet per man hour) | Estimated variance of productivity |
|---|---|---|
| 1 | 156 | 1516 |
| 2 | 162 | 1660 |
| 3 | 167 | 1748 |
| 4 | 184 | 1403 |
| 5 | 187 | 955 |
| 6 | 198 | 1467 |
| 7 | 149 | 2209 |
| 8 | 162 | 1508 |
| 9 | 190 | 1376 |
| 10 | 142 | 1252 |
| 11 | 179 | 1804 |
| 12 | 192 | 1640 |
| 13 | 156 | 1387 |
| 14 | 195 | 1643 |
| 15 | 108 | 2258 |
| 16 | 123 | 2117 |
| 17 | 161 | 2211 |
| 18 | 200 | 1086 |
| 19 | 143 | 1757 |
| 20 | 142 | 1760 |
| 21 | 145 | 1609 |
| 22 | 177 | 1060 |
| 23 | 200 | 1092 |
| 24 | 154 | 1195 |

## CHAPTER 6

## GROSS DATA TIME STUDY AND ITS COMPARATIVE PRECISION

Gross data time study differs from Detailed time study in that only one observation is made in each sample unit: the output per unit working time for a given operation. To take account of variations between work cycles performed within a sample unit, the typical sample units used for Gross Data time study are the working day and the working week. Output per man week is often recorded as a production statistic in logging operations although both the week and the day are too unreliable as measures of working time. Cutters, for example, may assist with other operations, such as snigging, or may waste time. A more reliable measure of working time is the hour. The number of man hours spent in a sample unit can be determined by time study. Field procedures similar to those developed above for Detailed time study would be used but only two elements would need to be distinguished: "cutting", composed of all the elements for Detailed time study shown in Table 15 (page 51 ) and "avoidable delays" as defined on page 50 .

To compare Detailed and Gross Data time study, Gross Data observations were derived from those collected by Detailed time study in each sample plot. The mean times per tree for all elements of cutting, distinguished in Detailed time study, except "avoidable delays", were added together. The mean volume per removed tree estimated from the tree volume equation was divided by the mean cutting time per tree to determine the output per man hour in each plot.

Results by Gross Data time study

Four stand variables were chosen for investigation by Gross Data time study. Three of these, mean basal area per removed tree, the number of trees removed per acre and predominant height seemed suitable for a predictive model because they would be available to management from sample plot records. The fourth, mean length of logs cut, would be less readily available, but it was chosen to investigate differences in productivity between cutting single sawlog lengths and cutting multiple lengths which provide two or more sawlogs when docked again at the sawmill.

A multiple linear regression equation on cutting productivity of all four stand variables was calculated.

$$P = 213.79 + \underset{(\pm 33.77)}{19.25}\,A - \underset{(\pm 0.25)}{0.29}\,F + \underset{(\pm 0.97)}{0.18}\,E - \underset{(\pm 2.41)}{3.38}\,H$$

using symbols given in Table 16 (page 55). The regression coefficent for mean length of sawlogs cut was negative. This was anomalous in that productivity when cutting longer logs, which require fewer cross-cuts, should have increased. Mean length of sawlogs cut was not correlated to any other stand variable which could account for anomaly, and it was not given any further consideration as a stand variable in the Gross Data time study.

Mean basal area and the number of trees removed per acre were found to be highly correlated with one another. The independent effects of either stand variable on cutting productivity could not be determined from the regression equation because of multicollinearity in the regression (Wonnacott and Wonnacott, 1969). It was decided to investigate separate regression models for mean basal area and the number of trees removed per acre, with and without predominant height in each case. The models and some relevant statistics are given in Table 20.

TABLE 20

Regression models for Gross Data time study

| Model | Equation | Residual sum of squares | Degrees of freedom |
|---|---|---|---|
| I | $P = b_0 + b_1 A + b_2 E$ | 32571 | 21 |
| II | $P = b_0 + b_1 A$ | 33704 | 22 |
| III | $P = b_0 + b_1 F + b_2 E$ | 31479 | 21 |
| IV | $P = b_0 + b_1 F$ | 32406 | 22 |

* where P denotes cutting productivity in cubic feet per man hour, $b_0 \ldots b_2$ denote regression coefficients, and other symbols are interpreted in Table 16 (page 55).

A test described by Seal (1964) was used to compare model 1 with model II and Model III with model IV. No significant difference was found between the models in either pair and the simpler model in each pair was taken as the better. The "better" models could not, however, be compared by Seal's test because they had equal degrees of freedom. The model with the smallest residual mean square was taken as the best of the four Gross Data models tested, i.e.

$$P = 209.46 - \underset{(\pm 0.17)}{0.34} F$$

This model could be used to estimate the productivity of sawlog cutting for stands whose characteristics lie within the ranges covered by field studies for this thesis (see page 48 and Appendix G). The precision of the estimate could be measured by the residual variance of the regression; i.e. the variance remaining after the effects of stand variables in the regression had been taken into account. This residual variance was 1473 cubic feet per man hour all squared.

The coefficient of determination ($R^2$) of the best Gross Data equation was 0.15. It showed that the stand variable in the equation accounted for only 15 per cent of the total variation in cutting productivity during the study. The remaining variation, expressed as the residual variance of the regression, was not accounted for.

<u>The precision of time study</u>

The variance of the cutting productivity quotient estimated for each Detailed time study plot was plotted against the quotient itself (Figure 6). The variance of cutting productivity estimated from the best regression equation obtained by Gross Data time study was also shown. The precision of estimates obtained from Gross Data time

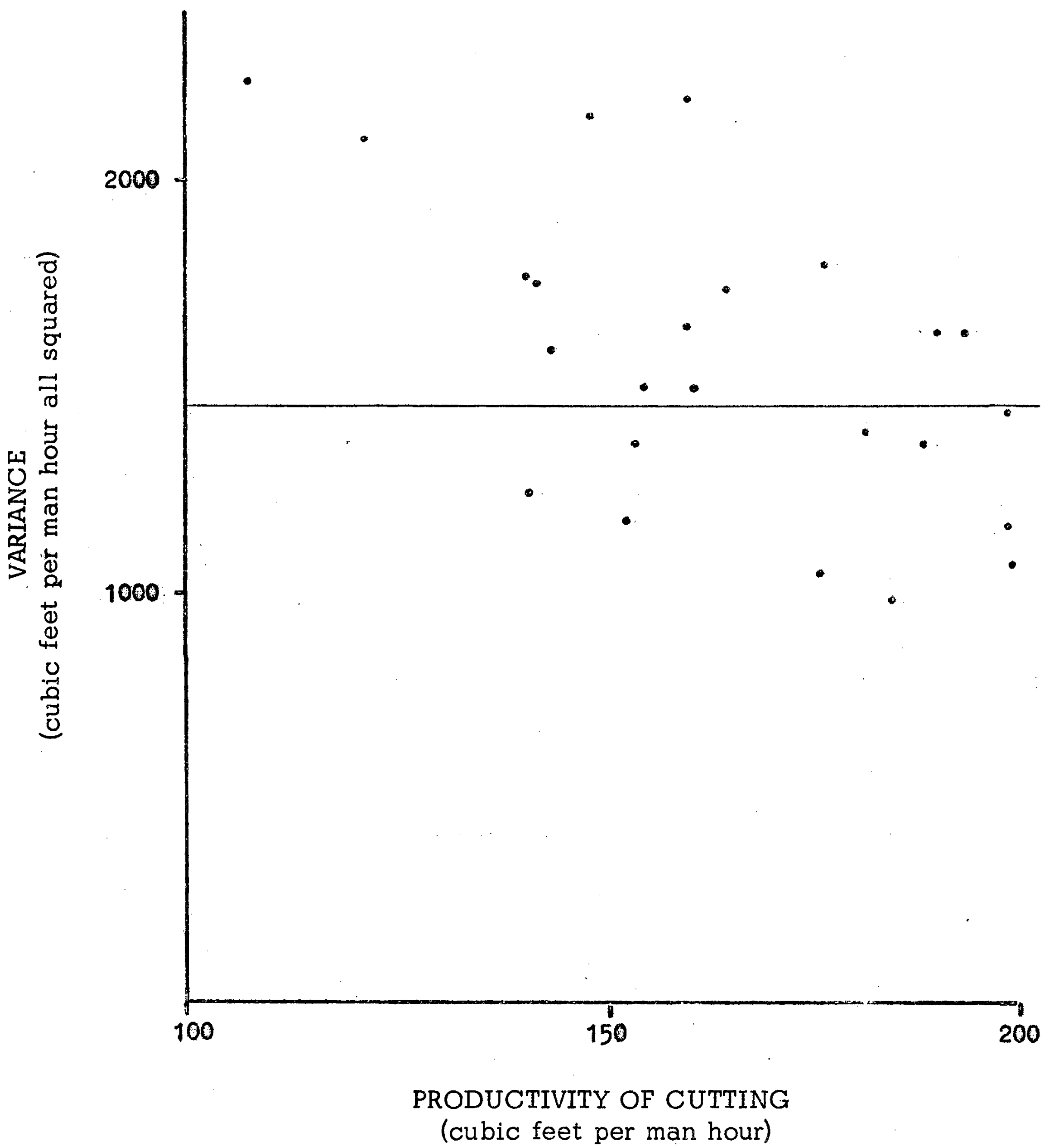



FIGURE 6

THE PRECISION OF DETAILED AND GROSS DATA TIME STUDY
(. Detailed Time Study, - Gross Data time study)

study was generally about the same as the precision of estimates obtained from the results of Detailed time study. Results of Gross Data time study, however, appeared to be more precise for low productivity values than the results of Detailed time study. This may not be true because the residual variance about the Gross Data regression equation was assumed to be homogeneous, but if it were true, it could have practical implications for future studies covering wide ranges of stand conditions since low productivity values and the stand conditions causing them may be given special consideration in wage determinations.

The studies for this thesis suggested the Gross Data and Detailed time study techniques gave equally precise results when applied to cutting operations, but neither technique explained much of the variation in cutting productivity. Only a small proportion of the variation in cutting productivity was attributed to differences between stands. The remaining variation could have been attributed to stand variables not taken into consideration; the weather, differences in performance level between cutters (reflecting differences in their physique, skill, experience, health, temperament and motivation) or chance factors.

Stand variables used in the studies were characteristics which could be determined from sample plot records or assessed fairly readily by management. Even if other stand variables had affected the productivity of cutting, it might not have been practical to have included them in a model of cutting productivity for predictive purposes. The weather was fine and dry throughout the periods of fieldwork, which took place during summer and early autumn. Occasionally felling was made difficult by strong winds but it is unlikely cutting productivity was affected significantly in this way. However, experience suggests performance differences between cutters could be responsible for some variations in cutting productivity. No studies have yet been carried out in Australia to determine the magnitude of this source of variation. If the variation in performance levels is considerable, it must be given special consideration in any future study of cutting productivity in Australia.

# CHAPTER 7

## COSTS OF CUTTING SAWLOGS IN NEW SOUTH WALES

Replies to a questionnaire, circulated among major plantation owners and sawmillers in the Australian, plantation grown softwood timber industry indicated that cutting is done almost entirely by contractors and the rates of pay for cutting are usually determined by direct negotiation between the contractors and their cutters. Almost all cutters are paid by results. Because rates of pay are determined in this way, they would vary throughout New South Wales and would almost certainly include subjective estimates of the effects of differences between stands on the productivity of cutting.

The aim of this investigation was to determine the effects of differences between stands on the cost per unit volume for cutting. To avoid subjective bias which might be present in negotiated piece rates, the investigation was based on the award rates of pay for cutters in New South Wales. The hourly award rate was divided by the productivity of cutting to obtain the cost per unit volume.

Detailed time study showed that differences in basal, and small end areas of removed trees, number of trees removed per acre, predominant height of stands, and mean length of logs cut affected the productivity of cutting. Gross Data time study showed the number of trees removed per acre had the greatest effect on cutting productivity. However, the number of trees removed per acre was strongly related to the mean basal area per removed tree and this relationship would reflect the thinning schedule applied to pre-war planted radiata pine in New South Wales and the Australian Capital Territory. Further research will be needed to determine the independent effects of mean basal area per removed tree and the number of trees removed per acre on cutting productivity.

The results of Gross Data time study were used to investigate cutting costs because the predictive equation was simpler than but as precise as the results of Detailed time study. Because the residual variance of the best Gross Data regression equation was so great and there are indications that much of it could be attributed to differences in performance level between cutters taking part in the study, the predictive model may not provide a good estimate of the average productivity of cutting. It should, however, give some idea of the way the current piece rate for cutting should be corrected when cutters are moved to a different stand.

## Award wages for cutting

The Timber Workers' Consolidated Award applies to cutters in New South Wales who are members of the Australian Timber Workers' Union, cutters whose employer is bound by the award, and cutters who work for a contractor hired by such an employer. The award assigns the minimum weekly rate for various classes of adult male employees in the timber industry. Pine cutters are represented by two such classes: "fallers" and "loaders, trimmers and employees cutting logs". The respective minimum weekly wage rates assigned in April 1970 to these classes were $52-40 and $47-50. These wages are paid for a normal working week of forty hours. Any employee instructed by his employer to work outside normal hours is entitled to overtime payment at the stipulated rate. Employees on time wages are entitled to ten public holidays each year and to twenty one consecutive days annual leave after twelve months continuous service. Pine cutters who operate and maintain their own chain saws are also entitled to an allowance of not less than $6-00 per week.

Under the award, an employer may introduce a system of payment by results. Employees must receive at least the minimum time rate and the piece rate should enable workers of average ability to earn at least $12\frac{1}{2}$ per cent more than their weekly time rate. Piece workers are entitled to three weeks annual leave, paid at the ordinary time rate for their classification, but are not entitled to paid public holidays. In subsequent calculations, it will be assumed that piece work cutters work 1960 hours per year or 40 hours per week for 49 weeks of the year.

The hourly wage payable to piece work cutters of average ability was divided by the estimated output per man hour to determine the cost per unit volume. Separate calculations were made for a single cutter and a team of two men. In the case of the team of two men it was assumed that the productivity of the team is twice that of the single cutter, that one man in the team uses a chain saw and is classified as a "faller" for wage payment purposes, and that his mate is classified as a "trimmer".

Figure 7 shows that cutting costs increase curvilinearly as the number of trees removed per acre increases within the range encountered in the study plots for this thesis (25 - 175 trees per acre). Over this range the cost per 100 cubic feet for a two man cutting team is about 7.5 cents less than that for a single cutter and the total change in cost per 100 cubic feet for either a single cutter or a two man team is 27.5 cents. If, therefore, a sawlog cutter or team of two cutters were moved from one stand to another, the present piece rate would need adjusting by some amount not exceeding 27.5 cents per 100 cubic feet, to compensate for changes in cutting productivity attributable to differences between stands.

Chain saw costs

Under the Timber Workers' Consolidated Award, cutters are entitled to an allowance of at least $6-00 per week for operating and maintaining their own chain saws. Cost Data for various chain saws were obtained from the Forestry and Timber Bureau to compare with the award allowance. These data are given in Appendix L. The cost of operating a chain saw is equal to the cost per machine hour divided by the output per machine hour for sawing. The cost per machine

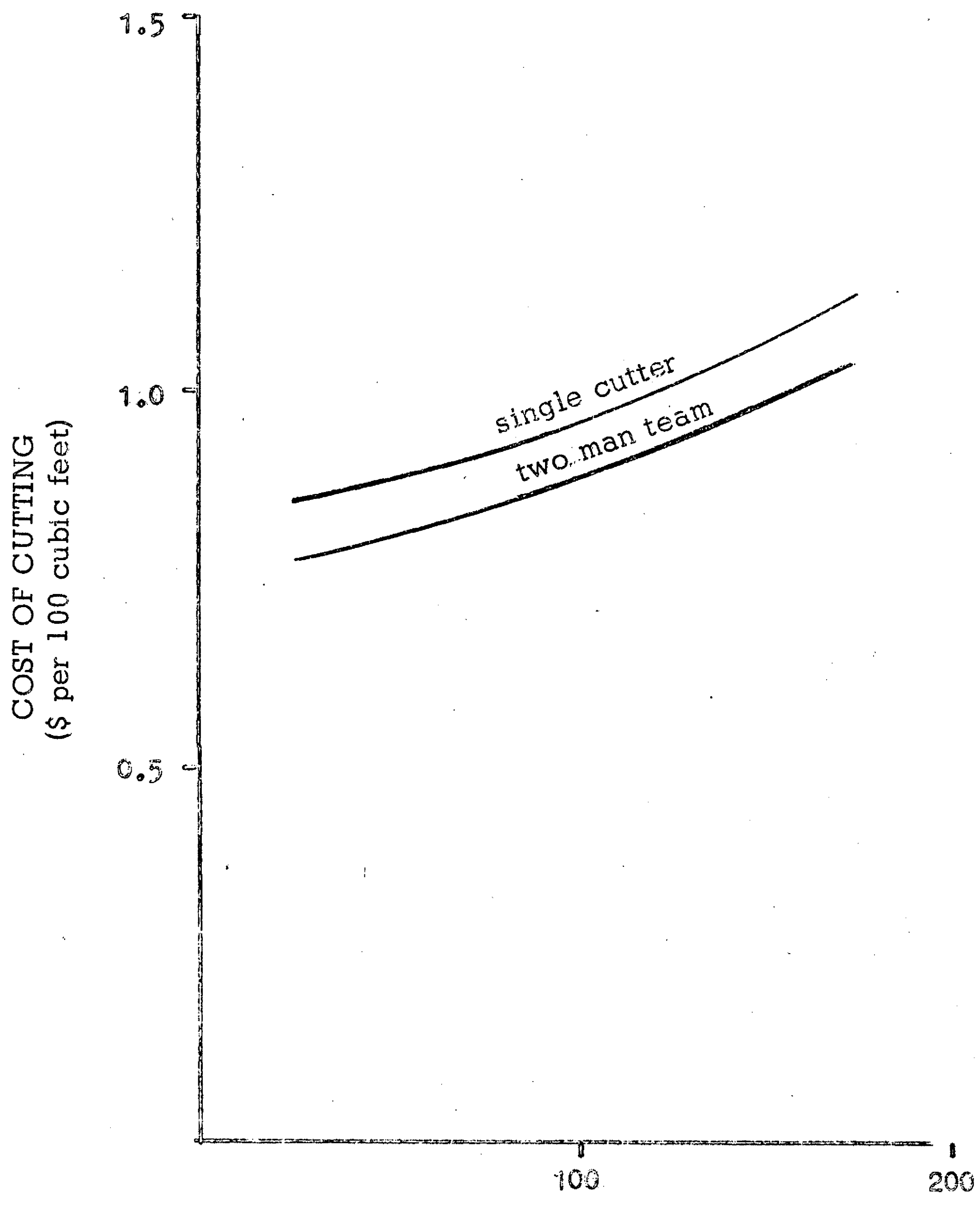



FIGURE 7

THE COST OF CUTTING SAWLOGS IN NEW SOUTH WALES hour for a chain saw depends on its annual use. This is equal to the number of man hours per annum spent on cutting multiplied by the fraction of cutting time spent on actual sawing. The fraction can be estimated from the equations in Table 17 (page 56 ) assuming actual sawing time is equal to the time spent on the elements "saw", "remove splinters from butt of felled tree" and "crosscut". Sawing output per machine hour is equal to the output per man hour from cutting multiplied by the fraction of cutting time spent on actual sawing. In Figure 8, the estimated cost per unit volume for using a chain saw in each study plot is plotted against the number of trees per acre removed. Costs are shown for two types of saw which represent the range used by cutters in pine plantations: saws with 20 inch cutter bars priced at $200 and saws with 20 inch cutter bars priced at $400. (Cost data on saws priced at $300 and saws with 30 inch cutter bars are also given in Appendix L). The more expensive types of chain saw have greater engine capacities. Results of a trial in which eleven different chain saws were operated in radiata pine by the same cutter (Report on chain saw tests, 1961) indicate that a greater engine capacity slightly increases the cutting rate for felling and more markedly increases the crosscutting rate. However, the state of maintenance probably has more effect on chain saw performance in practice than engine capacities. For this investigation, it was assumed that the more expensive saws do not have significantly better cutting rates or significantly less down time.

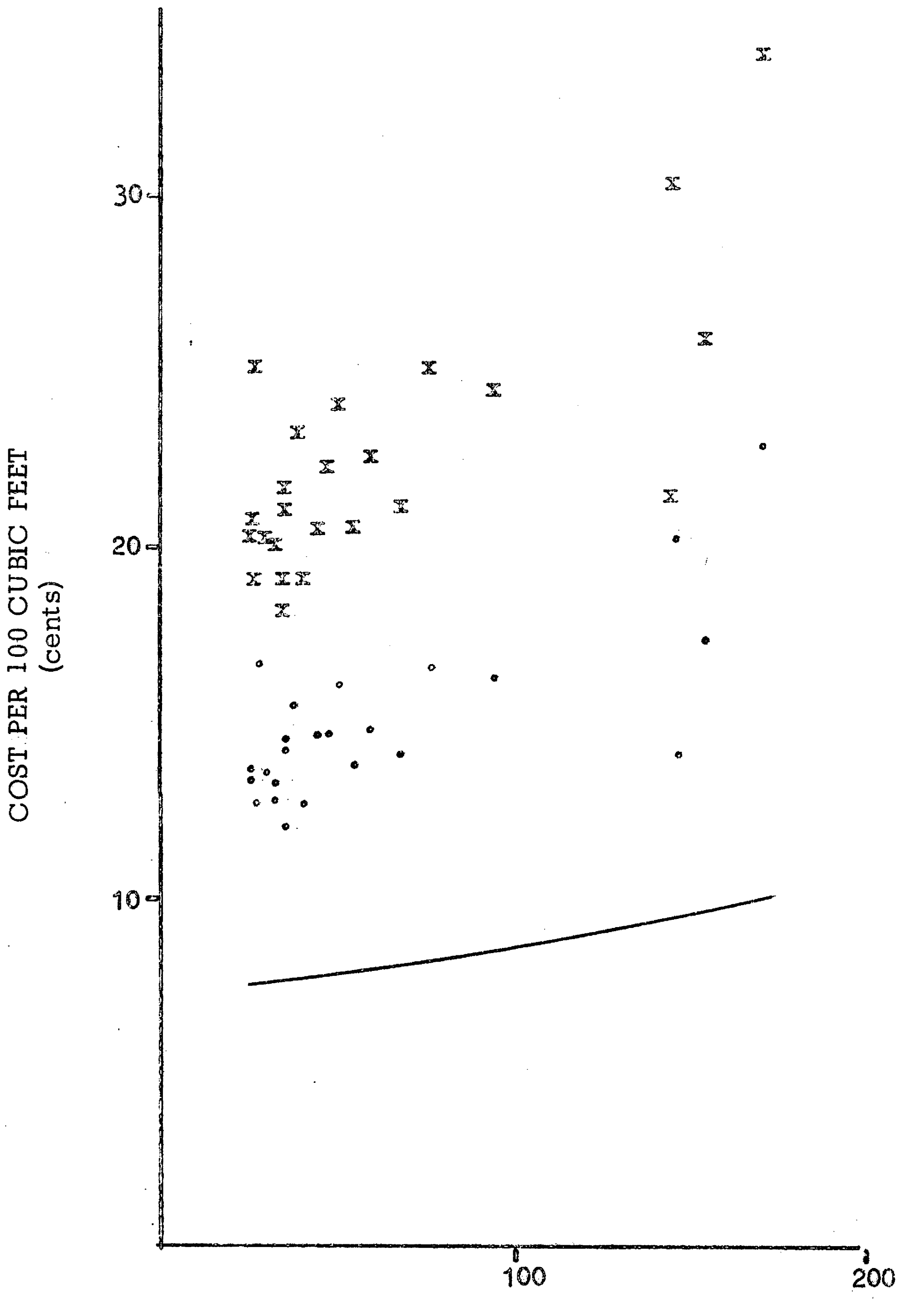



FIGURE 8

COST OF OPERATING AND MAINTAINING A CHAIN SAW
(x cost of a chain saw with 20 inch cutter bar, price $400)
(∘ cost of a chain saw with 20 inch cutter bar, price $200)
(– minimum chain saw allowance)

Figure 8 also shows the cost per unit volume of the minimum award allowance for a chain saw. The hourly value of the allowance was divided by the equation for predicting output per man hour from cutting (page 77 ).* Estimated costs for sawing are much greater than the minimum award allowance in every case. A minimum weekly allowance of $12-00 would be required to cover the estimated costs of a $200 saw and an allowance of $18-00 to cover the estimated costs of a $400 saw.

The estimated chain saw costs may, however, be erroneous because the Forestry and Timber Bureau have attempted to generalize costs for the variety of makes used by pine cutters. Saws would also vary considerably in age and state of maintenance and since few cutters keep detailed cost records, the Bureau's data would contain many assumptions, some of which might not be valid. More accurate data on chain saw costs are needed to provide a better basis for wage negotiations in situations where cutters are required to supply their own saws.

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*The 'hourly value of the allowance' is one fortieth of the weekly allowance in the Timber Workers Award for owning and operating a chain saw (page 84). A forty hour working week is being assumed.

# CHAPTER 8

# COSTING AND DESIGNING TIME STUDIES

## The cost of time study

Estimates were made of the cost of carrying out a study of twenty four sawlog cutting operations in New South Wales and the Australian Capital Territory using Detailed and Gross Data time study techniques. The field work for either study would involve 433 hours of time study and 4 hours per study plot for initial preparations and assessment of a final mensuration plot. About three months of office work would be required for Detailed time study but only about one month for Gross Data time study. A graduate forester could organize and carry out the entire Gross Data study but he would require the services of a technical assistant for the Detailed time study. The technical assistant would measure felled trees and assist with the preparation of Detailed time study data for computer handling. Estimated costs are given in Table 21 (page 90).

The Detailed time study would cost about $6800, the Gross Data study only $3200. Because the two techniques have equal precision, the cost per unit of precision of Gross Data time study would be about half that of Detailed time study. Results from Gross Data time study could be made available much more quickly than those of Detailed time study because less office work is involved. The analysis of Detailed time studies could also be delayed (by two to three months) while data are transferred from field sheets to punch cards for computer handling, a process which is not necessary in Gross Data time study because the data are much simpler.

TABLE 21

Costs of time study

| Item | Cost for Detailed time study $ | Cost for Gross Data time study $ |
|---|---|---|
| Field work | | |
| Wages for a graduate forester* | 2393 | 2393 |
| Wages for a technical assistant* | 1948 | - |
| Office work | | |
| Wages for a graduate forester | 1229 | 819 |
| Wages for a technical assistant | 905 | - |
| Card punching | 307 | 43 |
| Computer use | 58 | 2 |
| Total cost | 6840 | 3257 |

* Includes the cost of travelling allowances

Detailed time study would cost $3600 more than Gross Data time study and this extra cost can be regarded as the cost of extra information gained. This information would be most useful for a critical examination of present methods of cutting and for constructing simulation models of alternative methods. The methods used to cut sawlogs have not changed greatly since the introduction of chain saws but cutting is only one of the operations involved in harvesting. Cutting involves the preparation of logs for subsequent operations such as snigging, hauling and conversion at the mill and some aspects of cutting, in particular the direction in which trees are felled, the quality of trimming, the cross cutting pattern and track clearing done by cutters, affect the economics of both cutting and subsequent operations. Present cutting methods may have to be changed to allow developments in log transport and millyard handling to be introduced in the most economical way. If Detailed time studies are made of present cutting methods, the cost of the extra information gained could be recovered through reduced harvesting costs following method studies of all operations involved in harvesting.

<u>Designing future studies</u>

The present studies have shown that management can obtain useful information on cutting operations by work study. Such information could be particularly valuable for wage determinations, labour planning and comparative cost studies. However, time studies are expensive to carry out and analyse and particular attention should therefore be paid to the design of future studies to ensure the information wanted will be obtained.

Four main sources of variation in productivity must be sampled or eliminated in studies of cutting operations:

(a) fluctuations in the performance of an individual cutter

(b) differences in performance between cutters

(c) alternative work methods

(d) differences between stands.

Cutting consists of a sequence of sub-operations often performed on groups of trees rather than individuals. Some elements of cutting do not occur on every tree but only periodically throughout each working day. It is thus impractical to carry out a time study of cutting for less than a day. Fluctuations in the performance of individual cutters from day to day cause variations in cutting productivity which can be reduced by carrying out a study of several days duration or by sampling several days at each work site. Either could be expensive since Gross Data time study costs about $44 per day in the field and Detailed time study costs about $80. Research is needed to determine the magnitude and significance of fluctuations in the performance of individual cutters. The question of cutters' reactions to time study should also be investigated to show whether the first days results for each cutter in a study should be discarded.

Differences in performance between cutters are important in any study where conclusions about the whole population must be drawn from a sample. The present study has indicated that performance differences account for a considerable amount of the total variation in productivity observed in a study involving three or more cutters. It may be possible to reduce this variation by stratifying the population of cutters and sampling within each stratum. Previous performance levels indicated by production data would provide one means of stratification, performance capacity measured with an ergonometer in a laboratory could provide another. Research is needed to estimate the magnitude of performance differences among Australian cutters and to find a suitable method for stratification.

Where alternative work methods are being studied, the same cutters should be compared to eliminate variation due to performance differences. Alternative work methods can be compared by simulation, as illustrated above, or by comparative field trials as used by Whiteley (1972).

Simple comparative trials of alternative work methods can be held in the same stand to eliminate variation due to stand differences. However, in work studies for wage determinations, the effects of stand differences on the productivity of cutting must be taken into account. Where plantations are widely scattered it may not be possible to study the same sample of cutters in each different stand as was done at Sunny Corner in the present study. Two alternative ways of determining the effects of differences between stands on cutting operations are:

(1) employ one or more cutters as statistical controls. The control cutters visit each study site in turn and work alongside the local cutters.

(2) Have one or more stands as statistical controls. Each cutter is studied in the control stand as well as in his local stands.

Neither of these techniques has yet been used in work studies of cutting in Australia.

Although the present study was confined to cutting operations, work study techniques can be applied to other components of, logging operations such as snigging and hauling and to other forest operations such as planting and tending. The same techniques can be applied to measure the productivity of more highly mechanized operations than cutting but additional studies would be required to determine the costs. Some data on the costs of owning and operating forest machinery in Australia have been published (de Vries, 1967) but most refer to machines used for logging in hardwood forests.

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SUMMARY

Two work studies of radiata pine cutting were undertaken to show how they can help solve some typical logging problems. The first study compared alternative methods of logging first thinnings in plantations near Bathurst, New South Wales. A regression equation for the mean cutting time per tree was calculated from time study data on present shortwood operations at Bathurst and applied to data on sample plots first thinned in 1965-1970 to estimate the cutting time spent on first thinnings over that period. The total merchantable volume yield from first thinnings in 1965-1970 was divided by the estimated total cutting time to obtain the average productivity in shortwood cutting. The same data were used to construct a simulation model and estimate the productivity of tree length cutting. Data on shortwood and tree length extraction were also obtained and analysed.

Using the above information, plant and labour requirements of alternative logging methods were predicted for 1972-1977. Shortwood operations would require more cutters than tree length but total labour requirements would be equal. Cutting shortwood and extracting by skidders with loading booms would be cheapest. Cutting tree length logs and extracting them with specially equipped industrial tractors, though dearer, might be safer. It would be yet more expensive to bunch tree length logs with winches and extract the bunches subsequently with

skidders, and most expensive of all would be shortwood extraction with 42 horsepower forwarders.

In the second study, the effects of differences between stands on the productivity of sawlog cutting operations were investigated by two alternative time study techniques namely Detailed time study and Gross Data time study.

Twenty four operations in New South Wales and the Australian Capital Territory were subdivided into work elements for Detailed time study. The mean time per tree spent on each element in each operation was determined and regression analysis used to find out which stand differences affected it. The regression equations were aggregated to estimate mean cutting time per tree. Cutting productivity is the quotient of mean volume per removed tree, estimated from a tree volume equation, and mean cutting time per tree. Its variance was calculated as a measure of its precision.

Observations for Gross Data time study were obtained by dividing the mean volume per removed tree for each operation by the mean cutting time per tree. Several regression models of the effects of stand differences were tested. The best Gross Data model gave results for cutting productivity as precise as those derived by Detailed time study.

Effects of stand differences on award wages for cutting were investigated using the best Gross Data equation. Chainsaw costs were also investigated, using Detailed time study results to determine the fraction of working time spent on actual sawing.

Stand differences accounted for only 15 per cent of the total variation in cutting productivity. The remaining variation was probably caused by differences in cutter performance levels. This should be taken into consideration in the design of future studies. Gross Data time study would cost only half as much as Detailed time study but the latter can provide extra information for developing, simulating and comparing alternative methods.

The following table shows the effects of differences between stands with regard to the number of trees removed per acre on the productivity and cost per unit volume for cutting.

| Number of trees removed per acre | Cutting productivity (cubic feet per man hour) | Cost ($ per 100 cubic feet) |
|---|---|---|
| 25 | 201 | 0.85 |
| 50 | 192 | 0.86 |
| 75 | 184 | 0.93 |
| 100 | 175 | 0.97 |
| 125 | 167 | 1.02 |
| 150 | 158 | 1.08 |
| 175 | 150 | 1.14 |

It is assumed that weekly wages specified by the timber Workers Consolidated award (April 1970) are paid together with an incentive payment for piece work and an allowance for owning and operating a chain saw. A proportional part of the pay for the annual leave is included and a forty hour working week is assumed.

# APPENDIX A

## A SCHEME FOR SUBDIVIDING CUTTING OPERATIONS INTO ELEMENTS FOR TIME STUDY

Elements of cutting work can be defined by a description of each element and the actions which mark its beginning and end.

Collect tools begins when a cutter starts movement with the intention of collecting tools. The cutter may also deposit any tools he has in hand before collecting the tools he requires. The element ends when he starts to return to the work place with the tools he requires.

Walk to tree begins when the cutter starts to walk, having the appropriate tools in hand. The element ends when he reaches the tree or interrupts his journey to perform some other element. A cutter must often interrupt the performance of some other element such as "trim branches" to perform the element "walk to tree". When two trees lie so close together that the interruption is negligible, they may be described as adjacent.

Clear debris from base of tree begins when the cutter touches the first piece of debris and ends when he lets go of the last piece.

Inspect and prepare to fell begins when the cutter starts to look around and ends when he ceases to do so. The cutter may walk around while performing the element.

Saw begins when the chain saw starts to cut into the tree and ends when it jams in the cut, the tree hits the ground or the tree becomes lodged in the crown of another tree.

Remove splinters from butt of felled tree starts when the cutter raises his saw to the splinter and ends when the splinter is cut off.

Trim branches begins when the cutter first raises his axe to chop a branch off a tree and ends when he chops the last branch off the tree or group of adjacent trees.

Measure log lengths (or billet lengths) begins when the cutter places his measuring stick on the butt of the first log or billet and ends when he marks on the small end of the log or billet the position at which it will be crosscut. Alternatively the element ends when he marks the last log or billet in a group of adjacent trees.

Walk to log is defined in a similar way to "walk to tree" but is performed when a cutter walks to a specific log which has been marked for crosscutting or actually crosscut.

Crosscut begins when the saw starts to cut the tree at the point of crosscutting and ends when the saw jams in the cut or the cut is completed. The cutter may cut off the unmerchantable top of a tree with his axe during trimming.

Pick up billet, carry to stack and put down begins when the cutter touches the billet. He picks it up, throws it towards the stack or carries it, and places it on the stack. He may then adjust its position. The element ends when the cutter lets go the billet and may be interrupted when he uses his axe to perform the element "trim branch stubs on billet". If the position of a billet on a stack is adjusted later, the element is an unavoidable delay.

Trim branch stubs on billet begins when the cutter chops the first branch stub on a billet and ends when he chops the last branch stub on that or some adjacent billet.

Spiking is a suboperation composed of the elements "collect tools", "walk to log (or billet)" and "trim branch stubs on billet". It is performed by sawlog cutters after logs have been snigged to roadside.

Clear slash from outrow begins when the cutter touches the first piece of slash. He may walk from one piece of slash to another. The element ends when he lets go the last piece of slash he intends to clear.

Cut and clear hardwood debris in outrow is a suboperation composed of any of the above elements which are performed in order to cut up pieces of hardwood debris lying on or across the outrow and to clear such pieces as the cutter can lift.

Chain saw maintenance begins when the cutter shows his intention to perform the element. The tasks performed include refueling, refilling with oil, sharpening the chain, cleaning etc. The cutter may also collect the necessary tools for the task and, on completing the maintenance, test the chain saw on a piece of unmerchantable wood. The element ends when the cutter returns to the work place with a serviceable saw.

Rest and meal breaks

Delays begin and end appropriately. Delays may be classified as "unavoidable" or "avoidable". In this study, the following delays were considered "unavoidable".

faulty starting of a chain saw

freeing a chain saw jammed during felling

dislodging a lodged tree

throwing aside slash during trimming

sharpening an axe

freeing a chain saw jammed during crosscutting

the cutter's personal needs

adjustments to clothing

interruption by a third party engaged on supervision

adjusting stacked billets

walking to unmerchantable logs or billets and crosscutting them

# APPENDIX B

## DATA ON SHORTWOOD CUTTING AT SUNNY CORNER

TABLE 22

Data on Cutter 1

| | Mean basal area per removed tree (square feet) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.29 | 0.29 | 0.23 | 0.21 | 0.26 | 0.19 | 0.18 | 0.18 |
| | Mean stack volume (cubic feet) | | | | | | | | |
| | 71 | 47 | 18 | 82 | 45 | 22 | 83 | 52 | 22 |
| Element Symbol* | Mean times per tree (minutes) | | | | | | | | |
| 1 | 0.02 | 0.03 | 0.03 | 0.05 | 0.06 | 0.04 | 0.02 | 0.03 | 0.04 |
| 2 | 0.16 | 0.19 | 0.19 | 0.20 | 0.14 | 0.20 | 0.17 | 0.16 | 0.18 |
| 3 | 0.02 | 0.03 | 0.02 | 0.03 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| 4 | 0.11 | 0.14 | 0.18 | 0.13 | 0.10 | 0.10 | 0.08 | 0.11 | 0.10 |
| 5 | 0.21 | 0.26 | 0.23 | 0.18 | 0.18 | 0.20 | 0.15 | 0.18 | 0.18 |
| 6 | 0.06 | 0.00 | 0.00 | 0.05 | 0.00 | 0.06 | 0.00 | 0.00 | 0.01 |
| 7 | 0.23 | 0.31 | 0.41 | 0.34 | 0.75 | 0.29 | 0.13 | 0.17 | 0.21 |
| 8 | 0.08 | 0.03 | 0.02 | 0.02 | 0.03 | 0.06 | 0.03 | 0.05 | 0.04 |
| 9 | 0.14 | 0.16 | 0.18 | 0.14 | 0.14 | 0.15 | 0.15 | 0.17 | 0.14 |
| 10 | 1.37 | 1.62 | 1.80 | 1.52 | 1.02 | 1.82 | 0.92 | 1.10 | 0.95 |
| 11 | 0.01 | 0.11 | 0.05 | 0.01 | 0.00 | 0.01 | 0.04 | 0.02 | 0.03 |
| 12 | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | 0.08 | 0.05 | 0.03 | 0.03 |
| 13 | 0.10 | 0.11 | 0.13 | 0.12 | 0.10 | 0.14 | 0.10 | 0.11 | 0.10 |
| 14 | 0.24 | 0.26 | 0.23 | 0.25 | 0.18 | 0.32 | 0.14 | 0.16 | 0.14 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.08 | 0.09 | 0.04 | 0.03 | 0.04 | 0.08 | 0.03 | 0.06 | 0.04 |
| 17 | 0.20 | 0.27 | 0.27 | 0.23 | 0.20 | 0.24 | 0.20 | 0.19 | 0.19 |
| 18 | 0.15 | 0.24 | 0.22 | 0.15 | 0.12 | 0.17 | 0.09 | 0.10 | 0.09 |
| 19 | 0.00 | 0.01 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 | 0.00 | 0.02 | 0.05 | 0.09 |
| 21 | 0.43 | 0.41 | 0.50 | 0.47 | 0.37 | 0.44 | 0.43 | 0.37 | 0.33 |
| 22 | 0.68 | 0.64 | 0.81 | 0.84 | 0.57 | 0.64 | 0.64 | 0.55 | 0.42 |
| 23 | 0.09 | 0.09 | 0.06 | 0.05 | 0.03 | 0.04 | 0.03 | 0.02 | 0.03 |
| 24 | 0.00 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 |
| 25 | 0.28 | 0.55 | 0.15 | 0.25 | 0.15 | 0.27 | 0.13 | 0.12 | 0.06 |
| 26 | 0.00 | 0.06 | 0.11 | 0.16 | 0.05 | 0.03 | 0.09 | 0.00 | 0.00 |
| 27 | 0.06 | 0.16 | 0.06 | 0.10 | 0.06 | 0.24 | 0.09 | 0.08 | 0.20 |
| 28 | 1.63 | 1.70 | 2.74 | 2.48 | 1.76 | 1.56 | 1.51 | 2.15 | 2.31 |

* see Table 2 (page 19)

TABLE 23

Data on Cutter 2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean basal area per removed tree (square feet) | | | | | | | | |
| | 0.26 | 0.25 | 0.25 | 0.22 | 0.21 | 0.25 | 0.19 | 0.19 | 0.18 |
| | Mean stack volume (cubic feet) | | | | | | | | |
| | 77 | 41 | 15 | 60 | 40 | 19 | 63 | 43 | 23 |
| Element Symbol* | Mean times per tree (minutes) | | | | | | | | |
| 1 | 0.02 | 0.01 | 0.05 | 0.03 | 0.05 | 0.05 | 0.02 | 0.00 | 0.06 |
| 2 | 0.14 | 0.14 | 0.15 | 0.15 | 0.14 | 0.18 | 0.15 | 0.14 | 0.15 |
| 3 | 0.00 | 0.03 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.11 | 0.10 | 0.08 | 0.09 | 0.10 | 0.14 | 0.11 | 0.07 | 0.08 |
| 5 | 0.18 | 0.14 | 0.16 | 0.20 | 0.14 | 0.22 | 0.17 | 0.16 | 0.17 |
| 6 | 0.07 | 0.02 | 0.04 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 0.35 | 0.29 | 0.48 | 0.18 | 0.24 | 0.23 | 0.15 | 0.21 | 0.15 |
| 8 | 0.04 | 0.01 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.00 | 0.01 |
| 9 | 0.12 | 0.09 | 0.09 | 0.07 | 0.13 | 0.12 | 0.07 | 0.09 | 0.07 |
| 10 | 1.39 | 1.32 | 1.36 | 1.00 | 0.97 | 1.31 | 0.71 | 0.73 | 0.70 |
| 11 | 0.07 | 0.03 | 0.01 | 0.05 | 0.05 | 0.06 | 0.03 | 0.05 | 0.01 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.02 | 0.02 | 0.08 | 0.04 |
| 14 | 0.31 | 0.32 | 0.30 | 0.24 | 0.24 | 0.27 | 0.18 | 0.20 | 0.17 |
| 15 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| 16 | 0.01 | 0.02 | 0.05 | 0.02 | 0.03 | 0.03 | 0.01 | 0.00 | 0.01 |
| 17 | 0.23 | 0.21 | 0.20 | 0.20 | 0.18 | 0.26 | 0.16 | 0.17 | 0.16 |
| 18 | 0.20 | 0.19 | 0.19 | 0.14 | 0.13 | 0.16 | 0.09 | 0.10 | 0.09 |
| 19 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 |
| 21 | 0.56 | 0.55 | 0.33 | 0.46 | 0.40 | 0.45 | 0.37 | 0.37 | 0.31 |
| 22 | 0.83 | 0.85 | 0.56 | 0.75 | 0.61 | 0.77 | 0.66 | 0.64 | 0.51 |
| 23 | 0.13 | 0.11 | 0.07 | 0.06 | 0.07 | 0.05 | 0.04 | 0.04 | 0.03 |
| 24 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 |
| 25 | 0.42 | 0.22 | 0.51 | 0.17 | 0.32 | 0.34 | 0.15 | 0.14 | 0.18 |
| 26 | 0.01 | 0.01 | 0.03 | 0.10 | 0.08 | 0.22 | 0.08 | 0.10 | 0.05 |
| 27 | 0.09 | 0.03 | 0.00 | 0.04 | 0.02 | 0.03 | 0.08 | 0.04 | 0.06 |
| 28 | 0.56 | 0.61 | 0.06 | 0.47 | 0.53 | 0.60 | 0.31 | 0.05 | 0.39 |

* see Table 2 (page 19)

TABLE 24

Data on Cutter 3

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean basal area per removed tree (square feet) | | | | | | | | |
| | 0.23 | 0.26 | 0.25 | 0.23 | 0.24 | 0.29 | 0.29 | 0.19 | 0.21 |
| | Mean stack volume (cubic feet) | | | | | | | | |
| | 55 | 34 | 14 | 83 | 33 | 20 | 55 | 41 | 16 |
| Element Symbol* | Mean times per tree (minutes) | | | | | | | | |
| 1 | 0.00 | 0.02 | 0.07 | 0.04 | 0.04 | 0.08 | 0.04 | 0.04 | 0.07 |
| 2 | 0.29 | 0.26 | 0.27 | 0.28 | 0.27 | 0.22 | 0.22 | 0.21 | 0.24 |
| 3 | 0.05 | 0.01 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 |
| 4 | 0.10 | 0.25 | 0.15 | 0.13 | 0.17 | 0.12 | 0.10 | 0.08 | 0.10 |
| 5 | 0.26 | 0.21 | 0.21 | 0.14 | 0.18 | 0.12 | 0.19 | 0.17 | 0.22 |
| 6 | 0.12 | 0.00 | 0.00 | 0.03 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 |
| 7 | 0.19 | 0.36 | 0.17 | 0.27 | 0.16 | 0.13 | 0.13 | 0.10 | 0.08 |
| 8 | 0.00 | 0.04 | 0.06 | 0.02 | 0.01 | 0.00 | 0.07 | 0.02 | 0.05 |
| 9 | 0.01 | 0.34 | 0.22 | 0.18 | 0.37 | 0.11 | 0.09 | 0.07 | 0.10 |
| 10 | 2.34 | 1.96 | 1.49 | 1.73 | 2.08 | 1.57 | 1.11 | 0.88 | 1.28 |
| 11 | 0.07 | 0.13 | 0.26 | 0.03 | 0.04 | 0.10 | 0.03 | 0.00 | 0.11 |
| 12 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 0.60 | 0.64 | 0.53 | 0.42 | 0.53 | 0.45 | 0.43 | 0.38 | 0.46 |
| 15 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 0.33 | 0.26 | 0.19 | 0.16 | 0.17 | 0.11 | 0.13 | 0.12 | 0.12 |
| 19 | 0.00 | 0.00 | 0.00 | 0.09 | 0.01 | 0.01 | 0.16 | 0.02 | 0.01 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 0.54 | 0.44 | 0.30 | 0.37 | 0.29 | 0.16 | 0.44 | 0.34 | 0.30 |
| 22 | 1.04 | 0.89 | 0.85 | 0.95 | 1.00 | 0.61 | 0.78 | 0.56 | 0.56 |
| 23 | 0.00 | 0.01 | 0.04 | 0.07 | 0.01 | 0.06 | 0.02 | 0.04 | 0.03 |
| 24 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25 | 0.52 | 0.45 | 0.34 | 0.49 | 0.33 | 0.61 | 0.30 | 0.43 | 0.57 |
| 26 | 0.19 | 0.46 | 0.15 | 0.16 | 0.05 | 0.01 | 0.17 | 0.21 | 0.14 |
| 27 | 0.43 | 0.11 | 0.14 | 0.09 | 0.05 | 0.00 | 0.05 | 0.05 | 0.00 |
| 28 | 1.95 | 2.04 | 0.59 | 2.64 | 1.20 | 1.08 | 1.18 | 0.70 | 0.33 |

* see Table 2 (page 19)

# APPENDIX C

## CONVARIANCE ANALYSIS OF SHORTWOOD CUTTING REGRESSIONS

TABLE 25

Testing a common constant

| Source of variance | Degrees of freedom | Uncorrected sums of squares | Mean square |
|---|---|---|---|
| Separate constants and coefficients for each cutter | 9 | 1026.58 | |
| Common constant | 7 | 1018.76 | |
| Difference | 2 | 7.82 | 3.91 |
| Residual about model with separate constants and coefficients | 18 | 7.10 | 0.39 |
| TOTAL | 27 | 1033.68 | |

The ratio of the difference mean square to the residual mean square was greater than the tabulated value of Fisher's F - statistic at the 95% level of probability. It was concluded that the constants differed significantly between cutters.

TABLE 26

Testing a common regression coefficient of

mean basal area per removed tree

| Source of variance | Degrees of freedom | Uncorrected sums of squares | Mean square |
|---|---|---|---|
| Separate constants and coefficients for each cutter | 9 | 1026.58 | |
| Common coefficient for mean basal area per removed tree | 7 | 1020.95 | |
| Difference | 2 | 5.63 | 2.82 |
| Residual about model with separate constants and coefficients | 18 | 7.10 | 0.39 |
| TOTAL | 27 | 1033.68 | |

The ratio of the difference mean square to the residual mean square was greater than the tabulated value of Fisher's F- statistic at the 95% level of probability. It was concluded that the coefficients on mean basal area per removed tree differed significantly between cutters.

TABLE 27

Testing a common regression coefficient

of mean stack volume

| Source of variance | Degrees of freedom | Uncorrected sums of squares | Mean square |
|---|---|---|---|
| Separate constants and coefficients for each cutter | 9 | 1026.58 | |
| Common coefficient for mean stack volume | 7 | 1016.80 | |
| Difference | 2 | 9.78 | 4.89 |
| Residual about model with separate constants and coefficients | 18 | 7.10 | 0.39 |
| TOTAL | 27 | 1033.68 | |

The ratio of the difference mean square to the residual mean square was greater than the tabulated value of Fisher's F - statistic at the 95% level of probability. It was concluded that the coefficients on mean stack volume differed significantly between cutters.

# APPENDIX D

## DATA ON LOGGING OPERATIONS AT TUMUT

TABLE 28

Cutting and bunching

| Cutter | Time (minutes) | | | Number of trees | | Volume | |
|---|---|---|---|---|---|---|---|
| | Cut | Rest* | Bunch | Cut | Bunch | Cut | Bunch |
| 4 | 162.14 | 74.52 | 159.90 | 65 | 65 | 245 | 245 |
| 5 | 241.14 | 56.04 | 158.17 | 35 | 48 | 171 | 243 |
| 6 | 188.04 | 100.82 | 80.00 | 63 | 69 | 420 | 459 |
| 7 | 227.35 | 95.63 | 115.10 | 39 | 40 | 362 | 365 |
| 8 | 109.54 | 59.44 | 111.54 | 46 | 46 | 212 | 212 |
| 9 | 510.60 | | | 82 | | 360 | |
| 10 | 161.00 | | | 31 | | 206 | |
| 11 | 191.55 | | | 38 | | 200 | |
| 12 | 226.50 | | | 31 | | 175 | |

* rest and meal breaks

TABLE 29

Data on the extraction of bunches by skidder

| Skidder | Machine time* (minutes) | Idle time* (minutes) | Volume (cubic feet) | Number of trips |
|---|---|---|---|---|
| A | 213.99 | 57.31 | 1538 | 30 |
| B | 214.02 | 64.44 | 1381 | 27 |
| C | 84.27 | 27.73 | 466 | 11 |
| D | 169.97 | 63.84 | 918 | 27 |

* defined in Table 6 (page 33 )

# APPENDIX E

## VOLUME YIELDS FROM FIRST THINNINGS IN THE BATHURST PLANTATIONS

### TABLE 30

Volumes removed in 1965 - 1970
(in thousands of cubic feet)

| Plantation | Year of thinning | | | | | |
|---|---|---|---|---|---|---|
| | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 |
| Glenwood | | | 155 | | | |
| Canobolas | 569 | 427 | 329 | 603 | 416 | 421 |
| Vulcan | | | | 89 | 65 | 152 |
| Gurnang | 194 | 431 | 245 | 322 | 136 | 257 |
| Jenolan | 477 | 576 | 264 | 587 | 814 | 498 |
| Sunny Corner | 210 | 318 | 477 | 799 | 121 | 531 |

### TABLE 31

Volumes to be removed in 1972 - 1977
(in thousands of cubic feet)

| Plantation | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
| Glenwood | | | 289 | | | |
| Canobolas | 747 | 655 | 480 | 509 | 621 | 636 |
| Vulcan | 618 | 373 | 377 | 297 | 583 | 286 |
| Gurnang | 243 | 170 | 246 | 182 | 228 | 212 |
| Jenolan | 102 | 318 | 440 | 100 | 265 | 371 |
| Sunny Corner | 395 | 530 | 403 | 382 | 615 | 594 |

# APPENDIX F

## COSTS OF FOREST MACHINERY

Cost data are given in Tables 32 and 33 below for the following machines:

(a) a 42 H.P. forwarder

(b) a 97 H.P. skidder equipped with a loading boom and winch

(c) a 40 H.P. industrial tractor equipped with a single drum winch and a light frame suitable for bunching

(d) a 97 H.P. skidder with winch

(e) a 40 H.P. industrial tractor equipped with a safety canopy, half tracks, double drum winch and a skid pan.

The method for costing forest machinery developed by the Forestry and Timber Bureau (de Vries, 1967) was used. Although this method is highly simplified and ignores such costs as administrative overheads, profit and income tax, it nevertheless provides an acceptable basis for comparative cost studies.

TABLE 32

Purchase prices of plant and equipment for log extraction

| Item | Price $ | Notes |
|---|---|---|
| 42 H.P. forwarder | 16,500 | |
| | | |
| 97 H.P. skidder | 24,030 | |
| Loading boom | 2,600 | |
| | | |
| 40 H.P. Industrial tractor | 3,900 | |
| Winch and skid frame for bunching | 300 | 1 |
| | | |
| 97, H.P. skidder | 24,030 | |
| | | |
| 40 H.P. industrial tractor | 3,900 | |
| Safety canopy | 180 | |
| Half tracks | 2,000 | 2 |
| Double drum winch | 1,210 | |
| Skid pan | 300 | |

[1] quote from a local manufacturer at Tumut. Another single drum winch was quoted at $905.

[2] quote of actual price unavailable. A reasonable estimate was used.

TABLE 33

Cost data for log extraction plant

| Item | Forwarder | Skidder with loading boom | Industrial tractor for bunching | Skidder | Industrial tractor for snigging |
|---|---|---|---|---|---|
| Purchase price | $16,500 | $26,630 | $4,200 | $24,030 | $7,590 |
| Expected life (machine hours) | 5000 | 6000 | 4800 | 6000 | 4800 |
| Fuel consumption (gallons/hour) | 1.5 | 2.0 | 0.6 | 2.0 | 0.6 |
| Purchase price of a set of tyres | $834 | $1,529 | $354 | $1,529 | $354 |
| Expected life of a set of tyres (machine hours) | 2000 | 2000 | 2000 | 2000 | 2000 |
| Maintenance & repair costs as a percentage of depreciation | 90% | 70% | 70% | 70% | 75% |

The cost of insurance is assumed to be 1 per cent of the average capital investment. The annual cost of the interest on invested capital is assumed to be 8 per cent of the average capital investment. The cost of fuel is 42 cents per gallon and the cost of oil is assumed to be one tenth of the cost of fuel per machine hour.

# APPENDIX G

## SAMPLE PLOTS FOR THE SAWLOG CUTTING STUDIES

TABLE 34

Locations of the study plots

| Study plot number | Plantation | Compartment | Age (years) | Cutters |
|---|---|---|---|---|
| 1 | Uriarra | 122 | 29 | 1 and 2 |
| 2 | Uriarra | 124 | 31 | 3 and 4 |
| 3 | Uriarra | 121 | 29 | 5 and 6 |
| 4 | Pierces Creek | 22 | 36 | 7 and 8 |
| 5 | Murraguldrie | 13 | 40 | 9 |
| 6 | Murraguldrie | 33 | 36 | 10 and 11 |
| 7 | Carabost | 6 | 39 | 12 |
| 8 | Carabost | 6 | 39 | 13 |
| 9 | Mannus | 52 | 32 | 14 |
| 10 | Mannus | 23 | 38 | 15 and 16 |
| 11 | Green Hills | 60 | 33 | 17 |
| 12 | Green Hills | 60 | 33 | 18 |
| 13 | Green Hills | 62 | 33 | 19 |
| 14 | Billapaloola | 22 | 35 | 20 |
| 15 | Billapaloola | 29 | 33 | 21 |
| 16 | Billapaloola | 30 | 33 | 22 |
| 17 | Billapaloola | 22 | 35 | 23 |
| 18 | Billapaloola | 1 | 39 | 24 |
| 19 | Billapaloola | 30 | 33 | 25 |
| 20 | Billapaloola | 30 | 33 | 26 |
| 21 | Billapaloola | 22 | 33 | 27 |
| 22 | Jenolan | 17 | 35 | 28 and 29 |
| 23 | Vulcan | 11 | 36 | 30 and 31 |
| 24 | Mullion Range | 39 | 36 | 32, 33 and 34 |

TABLE 35

Intensity of thinning

| Study plot number | Basal area per acre before thinning (square feet) | Basal area per acre after thinning (square feet) |
|---|---|---|
| 1 | 173 | 124 |
| 2 | 194 | 125 |
| 3 | 156 | 119 |
| 4 | 174 | 128 |
| 5 | 155 | 108 |
| 6 | 102 | 72 |
| 7 | 136 | 86 |
| 8 | 130 | 90 |
| 9 | 123 | 57 |
| 10 | 193 | 104 |
| 11 | 187 | 134 |
| 12 | 162 | 126 |
| 13 | 196 | 135 |
| 14 | 172 | 116 |
| 15 | 213 | 102 |
| 16 | 195 | 83 |
| 17 | 251 | 124 |
| 18 | 181 | 120 |
| 19 | 146 | 76 |
| 20 | 256 | 108 |
| 21 | 206 | 116 |
| 22 | 139 | 100 |
| 23 | 173 | 112 |
| 24 | 159 | 89 |

TABLE 36

Measured stand variables

| Study Plot number | Mean basal area per removed tree (square feet) | Mean small end section area (square feet) | Predominant height (feet) | Mean merchantable volume (cubic feet) |
|---|---|---|---|---|
| 1 | 1.01 | 0.24 | 115 | 31.4 |
| 2 | 0.98 | 0.22 | 120 | 32.3 |
| 3 | 1.02 | 0.28 | 124 | 33.5 |
| 4 | 1.34 | 0.32 | 121 | 45.3 |
| 5 | 1.73 | 0.37 | 111 | 55.8 |
| 6 | 1.07 | 0.30 | 99 | 28.8 |
| 7 | 1.38 | 0.27 | 130 | 51.8 |
| 8 | 1.10 | 0.28 | 114 | 34.2 |
| 9 | 0.83 | 0.31 | 121 | 23.7 |
| 10 | 1.56 | 0.47 | 122 | 49.3 |
| 11 | 1.16 | 0.36 | 126 | 37.9 |
| 12 | 1.29 | 0.33 | 129 | 45.9 |
| 13 | 1.19 | 0.38 | 106 | 32.7 |
| 14 | 1.34 | 0.35 | 128 | 47.5 |
| 15 | 0.64 | 0.37 | 110 | 12.4 |
| 16 | 0.75 | 0.38 | 111 | 16.4 |
| 17 | 0.85 | 0.26 | 131 | 27.6 |
| 18 | 1.91 | 0.53 | 117 | 61.2 |
| 19 | 0.89 | 0.30 | 111 | 24.5 |
| 20 | 0.94 | 0.34 | 105 | 24.2 |
| 21 | 0.95 | 0.28 | 107 | 26.5 |
| 22 | 1.50 | 0.28 | 110 | 48.9 |
| 23 | 1.79 | 0.37 | 113 | 61.4 |
| 24 | 1.13 | 0.21 | 103 | 34.4 |

TABLE 37

Measured stand variables

| Study plot number | Number of trees removed per acre | Number of trees per acre before thinning | Ground slope (degrees) | Mean length of sawlogs cut (feet) |
|---|---|---|---|---|
| 1 | 49 | 157 | 14 | 13 |
| 2 | 70 | 159 | 13 | 11 |
| 3 | 36 | 127 | 7 | 10 |
| 4 | 34 | 101 | 4 | 11 |
| 5 | 27 | 81 | 2 | 15 |
| 6 | 28 | 79 | 12 | 18 |
| 7 | 36 | 87 | 14 | 14 |
| 8 | 36 | 101 | 11 | 21 |
| 9 | 79 | 127 | 2 | 22 |
| 10 | 57 | 101 | 1 | 15 |
| 11 | 46 | 131 | 3 | 15 |
| 12 | 28 | 101 | 5 | 15 |
| 13 | 51 | 157 | 8 | 15 |
| 14 | 42 | 111 | 7 | 14 |
| 15 | 174 | 250 | 15 | 14 |
| 16 | 149 | 208 | 14 | 14 |
| 17 | 149 | 232 | 13 | 14 |
| 18 | 32 | 83 | 4 | 14 |
| 19 | 79 | 133 | 12 | 14 |
| 20 | 157 | 246 | 14 | 14 |
| 21 | 95 | 180 | 17 | 14 |
| 22 | 26 | 79 | 8 | 23 |
| 23 | 34 | 79 | 11 | 22 |
| 24 | 62 | 121 | 3 | 22 |

# APPENDIX H

## DATA COLLECTED BY DETAILED TIME STUDY

TABLE 38

Mean element times
(in minutes per tree)

| Study plot | Element* 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 0.32 | 0.27 | 0.05 | 0.70 | 0.00 | 0.19 | 0.34 |
| 2 | 0.01 | 0.24 | 0.04 | 0.43 | 0.00 | 0.03 | 0.56 |
| 3 | 0.01 | 0.35 | 0.12 | 0.34 | 0.02 | 0.11 | 0.38 |
| 4 | 0.02 | 0.32 | 0.16 | 0.69 | 0.01 | 0.21 | 0.23 |
| 5 | 0.24 | 0.46 | 0.19 | 1.01 | 0.06 | 0.26 | 0.32 |
| 6 | 0.27 | 0.21 | 0.14 | 0.53 | 0.01 | 0.29 | 0.19 |
| 7 | 0.15 | 0.34 | 0.21 | 1.13 | 0.05 | 0.12 | 0.30 |
| 8 | 0.11 | 0.30 | 0.11 | 0.39 | 0.01 | 0.19 | 0.28 |
| 9 | 0.21 | 0.29 | 0.19 | 0.65 | 0.01 | 0.27 | 0.21 |
| 10 | 0.78 | 0.30 | 0.27 | 1.56 | 0.02 | 0.22 | 0.38 |
| 11 | 0.17 | 0.28 | 0.16 | 0.51 | 0.04 | 0.13 | 0.22 |
| 12 | 0.13 | 0.31 | 0.18 | 0.47 | 0.01 | 0.23 | 0.34 |
| 13 | 0.05 | 0.28 | 0.23 | 0.99 | 0.00 | 0.19 | 0.17 |
| 14 | 0.00 | 0.43 | 0.35 | 0.84 | 0.07 | 0.00 | 0.36 |
| 15 | 0.05 | 0.20 | 0.10 | 0.29 | 0.00 | 0.12 | 0.12 |
| 16 | 0.03 | 0.20 | 0.13 | 0.40 | 0.00 | 0.07 | 0.14 |
| 17 | 0.16 | 0.29 | 0.34 | 0.54 | 0.00 | 0.19 | 0.22 |
| 18 | 0.00 | 0.28 | 0.30 | 1.22 | 0.08 | 0.12 | 0.23 |
| 19 | 0.00 | 0.18 | 0.24 | 0.34 | 0.00 | 0.06 | 0.13 |
| 20 | 0.24 | 0.15 | 0.15 | 0.39 | 0.00 | 0.11 | 0.08 |
| 21 | 0.00 | 0.24 | 0.19 | 0.47 | 0.00 | 0.18 | 0.17 |
| 22 | 0.00 | 0.50 | 0.21 | 0.57 | 0.02 | 0.03 | 0.41 |
| 23 | 0.48 | 0.48 | 0.40 | 1.33 | 0.21 | 0.15 | 0.17 |
| 24 | 0.01 | 0.22 | 0.07 | 0.52 | 0.00 | 0.10 | 0.37 |

* see Table 15 (page 51).

TABLE 39

Mean element times
(in minutes per tree)

| Study plot | Element* 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 1 | 3.92 | 0.20 | 0.30 | 0.77 | 0.25 | 0.89 | 0.84 |
| 2 | 4.22 | 0.00 | 0.05 | 0.69 | 0.02 | 0.86 | 1.63 |
| 3 | 3.00 | 0.09 | 0.08 | 0.69 | 0.22 | 0.48 | 0.82 |
| 4 | 3.90 | 0.31 | 0.18 | 1.00 | 0.51 | 0.67 | 1.09 |
| 5 | 5.59 | 0.00 | 0.28 | 0.98 | 0.07 | 0.62 | 1.58 |
| 6 | 3.45 | 0.20 | 0.18 | 0.60 | 0.31 | 0.45 | 0.58 |
| 7 | 3.39 | 0.00 | 0.00 | 1.23 | 0.08 | 0.64 | 1.64 |
| 8 | 3.31 | 0.20 | 0.00 | 0.79 | 0.10 | 0.51 | 0.42 |
| 9 | 2.06 | 0.14 | 0.24 | 0.64 | 0.29 | 0.40 | 0.71 |
| 10 | 4.15 | 0.39 | 0.24 | 1.54 | 0.84 | 1.08 | 2.61 |
| 11 | 2.50 | 0.14 | 0.24 | 0.61 | 0.19 | 0.59 | 0.63 |
| 12 | 3.62 | 0.12 | 0.36 | 0.76 | 0.18 | 0.80 | 0.73 |
| 13 | 3.67 | 0.23 | 0.29 | 0.62 | 0.19 | 0.57 | 0.68 |
| 14 | 3.82 | 0.05 | 0.38 | 0.77 | 0.01 | 0.74 | 0.86 |
| 15 | 0.76 | 0.11 | 0.19 | 0.25 | 0.09 | 0.31 | 0.24 |
| 16 | 0.99 | 0.05 | 0.24 | 0.27 | 0.04 | 0.32 | 0.32 |
| 17 | 3.29 | 0.20 | 0.31 | 1.05 | 0.13 | 0.88 | 0.63 |
| 18 | 4.13 | 0.17 | 0.38 | 0.84 | 0.11 | 0.82 | 1.28 |
| 19 | 2.16 | 0.07 | 0.21 | 0.46 | 0.07 | 0.43 | 0.37 |
| 20 | 2.06 | 0.09 | 0.15 | 0.33 | 0.17 | 0.29 | 0.39 |
| 21 | 2.60 | 0.26 | 0.34 | 0.82 | 0.24 | 0.65 | 0.59 |
| 22 | 4.16 | 0.07 | 0.32 | 0.90 | 0.04 | 0.64 | 0.51 |
| 23 | 5.86 | 0.20 | 0.28 | 0.96 | 0.19 | 0.45 | 0.95 |
| 24 | 4.81 | 0.02 | 0.47 | 0.95 | 0.16 | 0.85 | 0.33 |

* see Table 15 (page 51 ).

TABLE 40

Mean element times
(in minutes per trees)

| Study plot | Element* 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|
| 1 | 0.00 | 0.28 | 0.46 | 0.42 | 0.45 |
| 2 | 0.00 | 0.00 | 0.44 | 0.12 | 0.36 |
| 3 | 0.00 | 0.09 | 0.00 | 0.17 | 0.69 |
| 4 | 0.01 | 0.26 | 0.46 | 0.33 | 2.73 |
| 5 | 0.29 | 0.26 | 0.83 | 0.33 | 4.11 |
| 6 | 0.23 | 0.09 | 0.20 | 0.08 | 4.05 |
| 7 | 0.16 | 0.13 | 0.97 | 0.48 | 6.38 |
| 8 | 0.08 | 0.08 | 0.46 | 0.05 | 3.85 |
| 9 | 0.03 | 0.29 | 0.14 | 0.17 | 1.50 |
| 10 | 0.14 | 0.13 | 1.24 | 2.81 | 6.45 |
| 11 | 0.28 | 0.29 | 0.31 | 0.07 | 2.37 |
| 12 | 0.11 | 0.23 | 0.37 | 0.00 | 2.54 |
| 13 | 0.08 | 0.38 | 0.45 | 0.56 | 3.56 |
| 14 | 0.32 | 1.24 | 1.03 | 0.00 | 3.29 |
| 15 | 0.04 | 0.19 | 0.18 | 0.03 | 1.10 |
| 16 | 0.07 | 0.27 | 0.37 | 0.24 | 2.29 |
| 17 | 0.12 | 0.48 | 0.52 | 0.03 | 5.76 |
| 18 | 0.22 | 0.43 | 1.06 | 0.26 | 1.45 |
| 19 | 0.05 | 0.68 | 0.65 | 0.00 | 0.79 |
| 20 | 0.09 | 0.49 | 0.32 | 0.09 | 1.46 |
| 21 | 0.06 | 0.40 | 0.55 | 0.25 | 2.12 |
| 22 | 0.00 | 0.02 | 0.00 | 0.57 | 7.01 |
| 23 | 0.00 | 0.26 | 0.66 | 0.44 | 4.05 |
| 24 | 0.00 | 0.01 | 0.57 | 0.22 | 2.65 |

*see Table 15 (page 51 ).

# APPENDIX I

## SPECIAL STUDIES OF TRIMMING

Since trimming means cutting off branches with an axe as close to the stem as possible, it might be analogous to sawing. If so, then the time spent on trimming depends on the surface area cut. To test this hypothesis, a regression of time per tree for the element "trim branches" on the sum of squared diameters of branch knots sampled on that tree was calculated from the data on each cutter. Of thirty such regressions (Table 41), twenty five were significant at the 95 per cent level of probability.

The coefficient of each regression in Table 41 was plotted against the mean sum of squared diameters of sampled branch knots per tree for the study plot (Figure 9). Values of the regression coefficient tended to decrease as branchiness increased implying that the time spent on trimming depended on the aggregate thickness of branches trimmed rather than their section area. Regressions of the time per tree spent on the element "trim branches",on the sum of diameters of sampled branch knots were calculated from the same data. Twenty seven of the regressions (Table 42) were significant at the 95 per cent level of probability. Regressions of time per tree spent on the element "trim branches" on the number of sampled branch knots were also calculated but it was found that this measure of

## TABLE 41

Regression equations for effects of branchiness on trimming times in minutes per tree

| Plot | Cutter | Constant | Coefficient in J[1] | | Number of observations |
|---|---|---|---|---|---|
| 1 | 1 | 2.94 | 0.068 | (±0.020) | 35 |
| 1 | 2 | 2.34 | 0.068 | (±0.025) | 15 |
| 2 | 4 | 2.13 | 0.127 | (±0.025) | 63 |
| 3 | 5 | 2.25 | 0.069 | (±0.012) | 68 |
| 4 | 7 | 3.14 | 0.038 | (±0.014) | 37 |
| 4 | 8 | 1.45 | 0.139 | (±0.035) | 18 |
| 5 | 9 | 2.80 | 0.091 | (±0.094) | 52 |
| 6 | 10 | 1.93 | 0.093 | (±0.016) | 59 |
| 6 | 11 | 2.45 | 0.088 | (±0.023) | 18 |
| 7 | 12 | 2.05 | 0.086 | (±0.016) | 60 |
| 8 | 13 | 2.01 | 0.120 | (±0.016) | 50 |
| 9 | 14 | 1.15 | 0.117 | (±0.018) | 64 |
| 10 | 15 | 2.81 | 0.088 | (±0.028) | 35 |
| 11 | 16 | 0.88 | 0.052 | (±0.016) | 11 |
| 11 | 17 | 1.15 | 0.078 | (±0.009) | 52 |
| 12 | 18 | 1.47 | 0.105 | (±0.015) | 53 |
| 13 | 19 | 2.27 | 0.079 | (±0.011) | 58 |
| 14 | 20 | 2.24 | 0.057 | (±0.011) | 51 |
| 15 | 21 | 0.89 | 0.021 | (±0.010) | 59 |
| 16 | 22 | 0.39 | 0.086 | (±0.010) | 58 |
| 17 | 23 | 2.10 | 0.081 | (±0.018) | 59 |
| 18 | 24 | 2.18 | 0.068 | (±0.012) | 54 |
| 19 | 25 | 0.83 | 0.100 | (±0.010) | 60 |
| 20 | 26 | 0.92 | 0.077 | (±0.010) | 56 |
| 21 | 27 | 1.74 | 0.080 | (±0.028) | 56 |
| 22 | 28 | 3.92 | 0.006 | (±0.005) | 12 |
| 22 | 29 | 2.77 | 0.028 | (±0.027) | 23 |
| 23 | 30 | 2.69 | 0.047 | (±0.010) | 25 |
| 23 | 31 | 4.87 | 0.033 | (±0.026) | 25 |
| 24 | 32 | 2.60 | 0.085 | (±0.040) | 18 |
| 24 | 33 | 1.82 | 0.057 | (±0.041) | 21 |
| 24 | 34 | 4.89 | -0.002 | (±0.043) | 16 |

[1] where J is the surface area of sampled branch knots per tree in square inches.

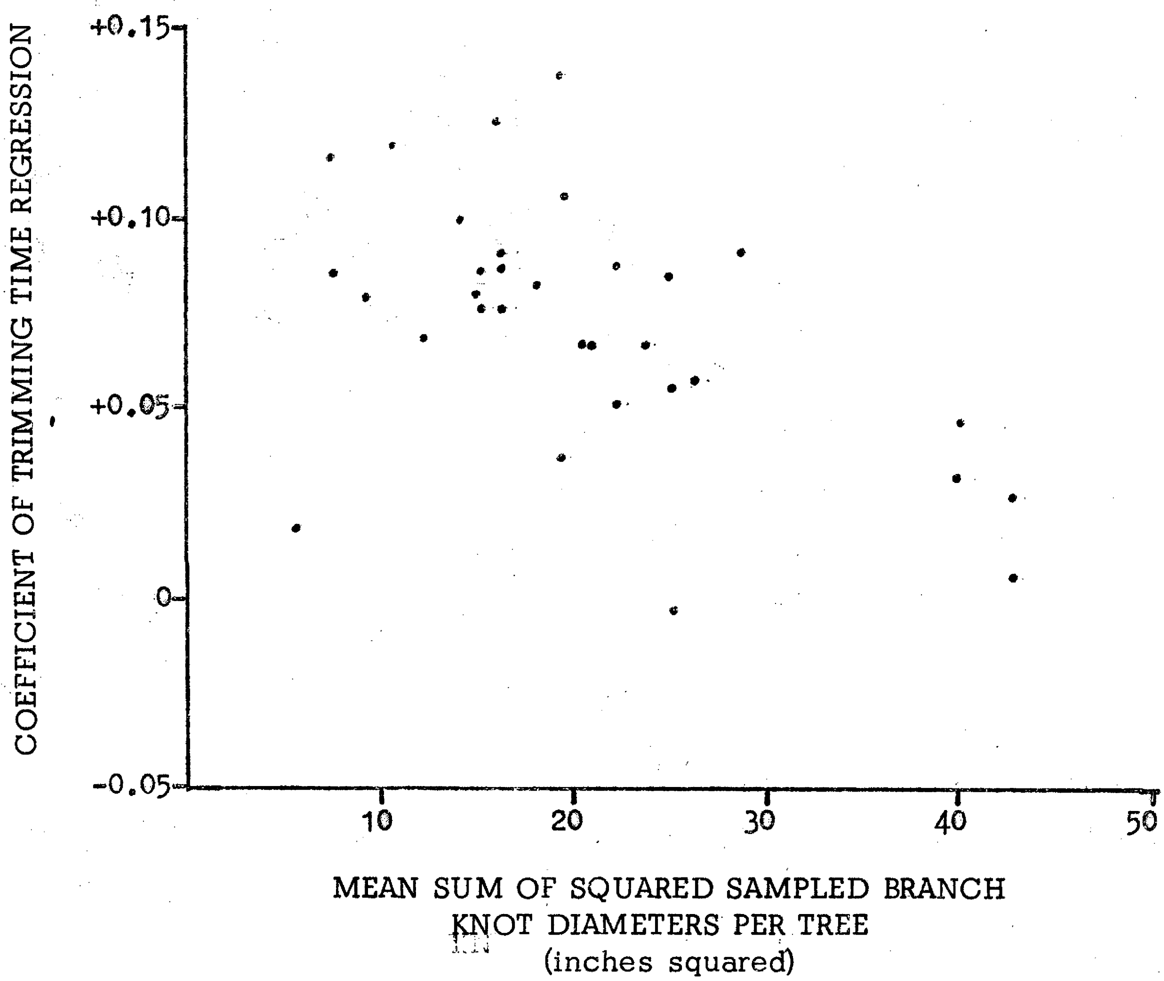


FIGURE 9

VARIATION AMONG COEFFICIENTS OF TRIMMING TIME REGRESSIONS

TABLE 42

Regression equations for effects of branchiness on trimming times in minutes per tree

| Plot | Cutter | Constant | Coefficient on K[1] | | Number of observations |
|---|---|---|---|---|---|
| 1 | 1 | 1.91 | 0.129 | (±0.031) | 35 |
| 1 | 2 | 1.98 | 0.094 | (±0.045) | 15 |
| 2 | 4 | 1.58 | 0.148 | (±0.035) | 63 |
| 3 | 5 | 1.76 | 0.103 | (±0.016) | 68 |
| 4 | 7 | 1.94 | 0.120 | (±0.032) | 37 |
| 4 | 8 | 0.84 | 0.173 | (±0.063) | 18 |
| 5 | 9 | 0.47 | 0.246 | (±0.027) | 52 |
| 6 | 10 | 0.88 | 0.171 | (±0.025) | 59 |
| 6 | 11 | 0.82 | 0.207 | (±0.046) | 18 |
| 7 | 12 | 0.97 | 0.142 | (±0.019) | 60 |
| 8 | 13 | 1.20 | 0.154 | (±0.019) | 50 |
| 9 | 14 | 0.61 | 0.185 | (±0.021) | 64 |
| 10 | 15 | 0.59 | 0.214 | (±0.041) | 35 |
| 10 | 16 | 0.18 | 0.109 | (±0.023) | 11 |
| 11 | 17 | 0.80 | 0.102 | (±0.014) | 52 |
| 12 | 18 | 0.86 | 0.152 | (±0.021) | 53 |
| 13 | 19 | 1.03 | 0.180 | (±0.022) | 58 |
| 14 | 20 | 0.80 | 0.147 | (±0.023) | 51 |
| 15 | 21 | 0.25 | 0.141 | (±0.018) | 59 |
| 16 | 22 | 0.24 | 0.124 | (±0.012) | 58 |
| 17 | 23 | 1.48 | 0.114 | (±0.020) | 59 |
| 18 | 24 | 1.49 | 0.126 | (±0.025) | 54 |
| 19 | 25 | 0.13 | 0.169 | (±0.017) | 60 |
| 20 | 26 | 0.34 | 0.162 | (±0.018) | 56 |
| 21 | 27 | 1.27 | 0.124 | (±0.031) | 56 |
| 22 | 28 | 1.91 | 0.076 | (±0.034) | 12 |
| 22 | 29 | 1.45 | 0.083 | (±0.049) | 23 |
| 23 | 30 | 0.70 | 0.155 | (±0.027) | 25 |
| 23 | 31 | 2.80 | 0.132 | (±0.053) | 25 |
| 24 | 32 | 1.96 | 0.121 | (±0.080) | 18 |
| 24 | 33 | 1.43 | 0.122 | (±0.068) | 21 |
| 24 | 34 | 3.65 | 0.050 | (±0.113) | 16 |

[1] where K is the sum of sampled branch knot diameters per tree in inches

branchiness did not affect trimming time as much as the sum of diameters of sampled branch knots.

Having established that the aggregate thickness of branches affected trimming time, a test was made to determine whether differences in hardness or brittleness between dead and live branches affected the time spent on trimming. The data on each tree on which both kinds of branch were trimmed during the study was used. If the majority of branch knots in a sample were "live" all branches in that whorl were classed as "live". The time spent on trimming dead branches on a given tree was divided by the sum of diameters of sampled dead branch knots. The mean difference between these values for all trees trimmed by a given cutter was divided by its standard error and compared with tabulated values of Student's t-statistic to test a null hypothesis. Twenty three of thirty such tests listed in Table 43 showed significant differences at the 95 per cent level of probability. It was concluded that the rate of trimming dead branches was the same as the rate of trimming live branches for radiata pine.

A regression of mean time per tree for the element "trim branches" and associated unavoidable delays (axe sharpening and throwing aside branches) on the mean sum of diameters of sampled branch knots was calculated. The regression, based on 24 observations, was significant at the 95 per cent probability level:-

TABLE 43

Differences in trimming dead and live branches of radiata pine (difference in trimming time in minutes per inch of sampled branch diameters along the merchantable stem)

| Plot | Cutter | Mean difference per tree | Standard error | Number of observations |
|---|---|---|---|---|
| 2 | 4 | 0.002 | (±0.046) | 51 |
| 3 | 5 | 0.017 | (±0.024) | 62 |
| 4 | 7 | -0.030 | (±0.036) | 29 |
| 4 | 8 | 0.018 | (±0.035) | 12 |
| 5 | 9 | -0.028 | (±0.032) | 43 |
| 6 | 10 | -0.081 | (±0.035) | 49 |
| 6 | 11 | -0.142 | (±0.058) | 15 |
| 7 | 12 | 0.020 | (±0.025) | 48 |
| 8 | 13 | 0.014 | (±0.026) | 45 |
| 9 | 14 | -0.001 | (±0.053) | 6 |
| 10 | 15 | -0.130 | (±0.111) | 10 |
| 10 | 16 | -0.128 | (±0.104) | 4 |
| 11 | 17 | -0.101 | (±0.036) | 39 |
| 12 | 18 | -0.039 | (±0.039) | 49 |
| 18 | 19 | -0.137 | (±0.046) | 32 |
| 14 | 20 | 0.147 | (±0.038) | 40 |
| 15 | 21 | -0.003 | (±0.067) | 8 |
| 16 | 22 | -0.142 | (±0.164) | 13 |
| 17 | 23 | 0.004 | (±0.074) | 32 |
| 18 | 24 | -0.022 | (±0.050) | 50 |
| 19 | 25 | 0.071 | (±0.084) | 25 |
| 20 | 26 | 0.070 | (±0.042) | 23 |
| 21 | 27 | -0.015 | (±0.036) | 38 |
| 22 | 28 | -0.101 | (±0.035) | 11 |
| 22 | 29 | -0.025 | (±0.024) | 21 |
| 23 | 30 | -0.098 | (±0.028) | 24 |
| 23 | 31 | -0.187 | (±0.041) | 23 |
| 24 | 32 | -0.165 | (±0.050) | 16 |
| 24 | 33 | -0.072 | (±0.047) | 12 |
| 24 | 34 | -0.099 | (±0.055) | 14 |

$$T = 0.40 + \underset{(\pm 0.02)}{0.19} K$$

where T denotes mean trimming time per tree in minutes
K denotes the mean sum of diameters of sampled branch knots per tree in inches

Figure 10 shows the relationship and the data on which it is based. Two investigations have been made into relationships between branchiness and tree dimensions of plantation grown radiata pine in Australia. Both investigations used data from young stands in which initial spacing trials had been established.

From measurements of branch diameters on 36 eight year old trees over a period of three years, Jacobs (1938) found a linear relationship between the section area of the stem at any point in the live crown and the total section area of branches above that point. The sample trees were equally distributed among plots of three different spacings and though significant differences were found between regressions for individual trees in the same spacing, for practical purposes they could be replaced by single regressions expressing an average for trees in the given spacing. The regression for average branching in a 12 by 12 feet spacing differed from the regressions for 9 by 9 and 6 by 6 feet spacings.

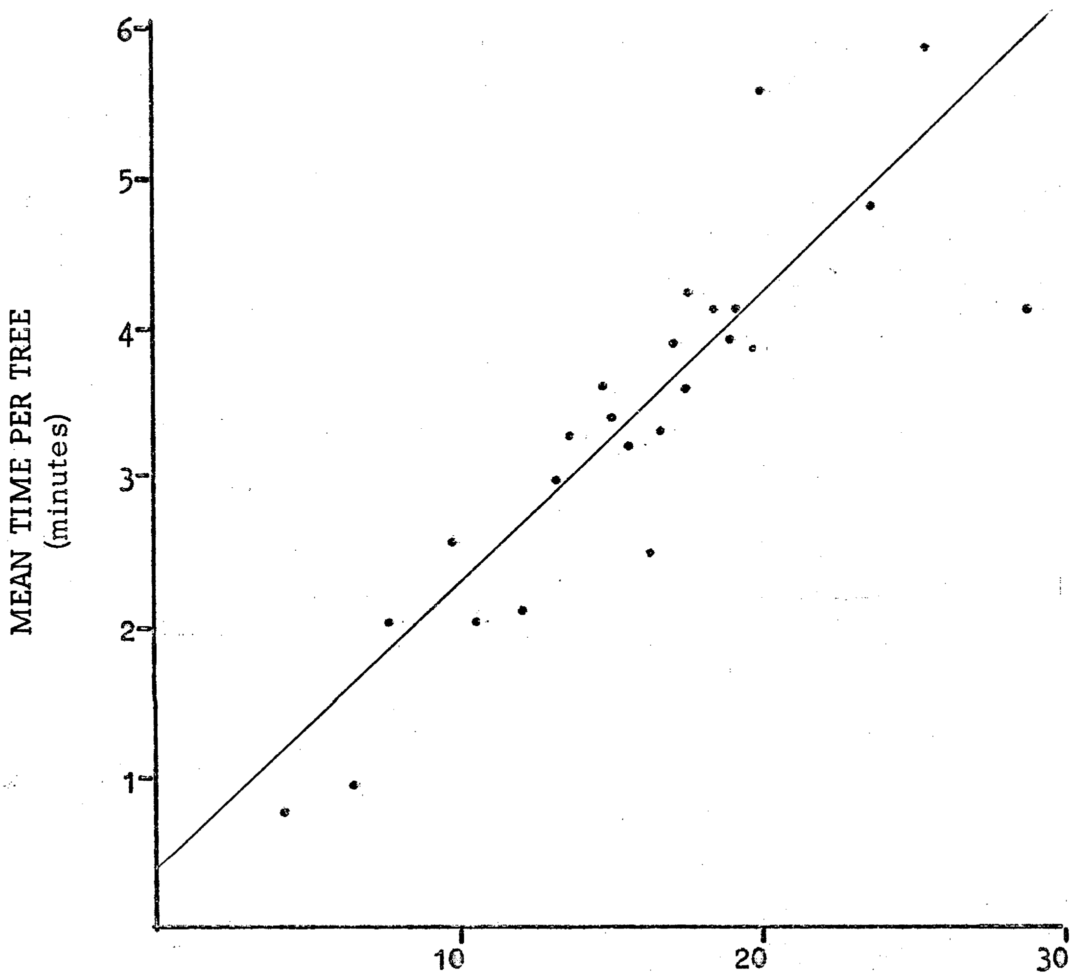


FIGURE 10

THE EFFECT OF BRANCHINESS
ON MEAN TRIMMING TIME PER TREE,
INCLUDING ASSOCIATED DELAYS

During an assessment of 18 plots equally distributed among six initial spacing treatments in 15 year old plantations, Cromer and Pawsey (1957) measured the diameter of each branch between 8 and 15 feet above ground level on the northern side of nine trees in each plot. They found that mean branch diameter was linearly related to breast height diameter and that whereas mean branch diameter was affected by spacing only to the extent that breast height diameter was affected by spacing, the regression of mean branch diameter on breast height diameter was affected by site, finer branching occurring on low quality sites.

The two results suggested the aggregate thickness of branches on the merchantable stem might be related to mean breast height diameter and mean taper.

# APPENDIX J

## COVARIANCES AND VARIANCES OF ELEMENT TIMES

| Element* | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 0.0345 | | | | | |
| 2 | 0.0017 | 0.0049 | | | | |
| 3 | 0.0018 | 0.0024 | 0.0066 | | | |
| 4 | 0.0226 | 0.0025 | 0.0059 | 0.0481 | | |
| 5 | 0.0005 | 0.0007 | 0.0011 | 0.0010 | 0.0013 | |
| 6 | 0.0067 | -0.0012 | -0.0004 | 0.0040 | -0.0004 | 0.0062 |
| 7 | -0.0004 | 0.0014 | -0.0029 | -0.0003 | -0.0009 | 0.0026 |
| 8 | 0.0291 | 0.0038 | 0.0002 | 0.0299 | 0.0020 | 0.0101 |
| 9 | 0.0089 | -0.0007 | 0.0017 | 0.0083 | -0.0005 | 0.0042 |
| 10 | -0.0009 | 0.0015 | 0.0022 | -0.0005 | -0.0006 | 0. |
| 11 | 0.0151 | 0.0029 | 0.0013 | 0.0201 | -0.0018 | 0.0046 |
| 12 | 0.0213 | -0.0017 | -0.0004 | 0.0174 | -0.0016 | 0.0073 |
| 13 | 0.0079 | -0.0008 | -0.0034 | 0.0058 | -0.0038 | 0.0011 |
| 14 | 0.0360 | 0.0003 | -0.0042 | 0.0544 | -0.0027 | 0.0054 |
| 15 | -0.0080 | 0.0040 | 0.0129 | 0.0060 | 0.0019 | -0.0056 |
| 16 | 0.0021 | -0.0002 | 0.0016 | 0.0009 | -0.0005 | 0.0010 |
| 17 | 0.0098 | -0.0003 | 0.0060 | 0.0321 | -0.0002 | -0.0020 |
| 18 | 0.0725 | 0.0059 | 0.0006 | 0.0692 | -0.0065 | 0.0080 |
| 19 | 0.0827 | 0.0369 | 0.0432 | 0.0936 | -0.0090 | 0.0178 |

| Element* | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 7 | 0.0114 | | | | | |
| 8 | 0.0136 | 0.2959 | | | | |
| 9 | -0.0028 | 0.0107 | 0.0104 | | | |
| 10 | -0.0007 | 0.0147 | 0.0011 | 0.0145 | | |
| 11 | 0.0107 | 0.0125 | 0.0078 | -0.0021 | 0.0548 | |
| 12 | -0.0001 | 0.0158 | 0.0139 | 0.0001 | 0.0200 | 0.0219 |
| 13 | 0.0104 | 0.0395 | 0.0052 | 0.0100 | 0.0211 | 0.0110 |
| 14 | 0.0240 | 0.0495 | 0.0075 | -0.0206 | 0.0585 | 0.0376 |
| 15 | -0.0065 | -0.0055 | -0.0009 | 0.0104 | -0.0133 | -0.0096 |
| 16 | 0.0019 | 0.0171 | 0.0022 | 0.0018 | 0.0220 | 0.0065 |
| 17 | 0.0034 | -0.0070 | -0.0009 | 0.0017 | -0.0305 | -0.0013 |
| 18 | 0.0137 | 0.0405 | 0.0284 | 0.0018 | 0.0642 | 0.0728 |
| 19 | 0.0050 | -0.1367 | 0.0249 | -0.0177 | 0.2118 | 0.0447 |

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| Element* | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|
| 13 | 0.0387 | | | | | |
| 14 | 0.0239 | 0.2187 | | | | |
| 15 | -0.0066 | -0.0219 | 0.0103 | | | |
| 16 | 0.0154 | 0.0557 | 0.0114 | 0.0695 | | |
| 17 | 0.0007 | 0.0006 | 0.0313 | 0.0086 | 0.0754 | |
| 18 | 0.0493 | 0.1432 | -0.0317 | 0. | 0.0458 | 0.3115 |
| 19 | 0.0224 | 0.0971 | -0.0689 | 0.0189 | 0.0259 | 0.3245 |

| Element* | 19 |
|---|---|
| 19 | 3.2050 |

*see Table 15 (page 51)

# APPENDIX K

## VARIANCES OF PRODUCTS AND QUOTIENTS

The following derivations were suggested by Dr.I.S.Ferguson of the Department of Forestry, Australian National University:

Given a product $V = M \times N = f(M, N)$,

the Taylor expansion about its mean $\bar{V}$ is

$$\bar{V} + dV = f(\bar{M}, N) + dM \frac{df}{dM} + dN \frac{df}{dN} + \ldots\ldots$$

Ignoring squares of small moments in M and N,

$$dV = dM\,N + dN\,M.$$

Now $\sigma_V^2 = E(V - \bar{V})^2$

$$= E(dV)^2$$

$$= E(dM\,N - dN\,M)^2$$

$$= E(dM^2N^2 + dN^2M^2 - 2\,dMdN\,N\,M)$$

$$= E(M - \bar{M})^2\,N^2 + E(N - \bar{N})^2\,M^2 - 2\,E(M - \bar{M})\,(N - \bar{N})\,N\,M$$

$$= \sigma_M^2\,N^2 + \sigma_N^2\,M^2 - 2\sigma_{MN}\,N\,M$$

Given a quotient $P = \frac{V}{T} = f(V,T)$,

the Taylor expansion about its mean $\overline{P}$ is

$$\overline{P} + dP = f(V,T) + dV \frac{df}{dV} + dT \frac{df}{dT} + \ldots\ldots .$$

Ignoring the squares of small moments in V and T

$$dP = dV \frac{1}{T} - dT \frac{V}{T^2}$$

Now

$$\sigma_P^2 = E(P - \overline{P})^2$$

$$= E(dP)^2$$

$$= E(dV \frac{1}{T} - dT \frac{V}{T^2})^2$$

$$= E(dV^2 \frac{1}{T^2} + dT^2 \frac{V^2}{T^4} - 2\, dV\, dT \frac{V}{T^3})$$

$$= E(V - \overline{V})^2 \frac{1}{T^2} + E(T - \overline{T})^2 \frac{V^2}{T^4} - 2\, E(V - \overline{V})(T - \overline{T}) \frac{V}{T^3}$$

$$= \sigma_V^2 \frac{1}{T^2} + \sigma_T^2 \frac{V^2}{T^4} - 2\, \sigma_{VT} \frac{V}{T^3}$$

$$= \frac{\sigma_V^2\, T^2 + \sigma_T^2\, V^2 - 2\sigma_{VT}\, VT}{T^4}$$

If V and T come from independent samples

$$\sigma_P^2 = \frac{\sigma_V^2\, T^2 + \sigma_T^2\, V^2}{T^4}$$

This relationship is reliable for samples greater than 30 individuals

and for $\frac{\sigma_V}{V}$ and $\frac{\sigma_T}{T} \gtrless 0.01$

# APPENDIX L

## COSTS OF CHAIN SAWS

TABLE 44

Chain saw costs varying with purchase price

| Item | Purchase price | | |
|---|---|---|---|
| | $200 | $300 | $400 |
| Resale value | $ 0 | $ 0 | $ 0 |
| Expected life (machine hours) | 1,000 | 1,000 | 1,000 |
| Annual insurance | $ 26 | $ 40 | $ 54 |
| Fuel price (cents per pint) | 6 | 6 | 6 |
| Fuel consumption (pints per machine hour) | 2½ | 3 | 3½ |
| Oil price (cents per pint) | 15 | 15 | 15 |
| Oil consumption (pints per machine hour) | 1½ | 1½ | 1½ |
| Initial outlay[1] | $ 10 | $ 11 | $ 13 |

[1] The initial outlay is the cost of a supply of fuel and oil which a cutter must outlay before he can commence to earn money with his chain saw. It is taken into account when calculating the cost of interest on invested capital. The interest rate is 8 per cent per annum.

TABLE 45

Chain saw costs varying with the length of cutter bar

| Item | Cutter bar length | |
|---|---|---|
| | 20 inches | 30 inches |
| Price of a chain and sprocket | $ 25 | $ 31 |
| Total cost of chains and sprockets[1] during the expected life of the saw | $400 | $500 |
| Cost of files during the expected life of the saw | $ 25 | $ 25 |

[1] The cost of repairs and maintenance other than chains, sprockets and files is 20 per cent of the depreciation costs.