ASSESSMENT OF LOGGING PRODUCTIVITY FOR A PINUS RADIATA THINNING OPERATION

L. S. KING*

SYNOPSIS

Two ways of using time study data for the pre-assessment of logging thinning production levels are discussed. One is by means of a detailed construction of the work content using the basic element times and the other is by development of linear models from multiple regression analysis. The latter method encourages wider use of the initial time study results and provides a better understanding of the factors that affect the planning and ultimate economics of logging thinning.

CONDITIONS OF ASSESSMENT

At Rotoehu Forest, production thinning commenced when *Pinus radiata*(initially 6 ft × 6 ft spacing) was 23 years of age.Management up to this point had consisted of low pruning to 7 ft. for all areas, while only portions of the stands under discussion were pruned to 17 ft and thinned to waste at 11 to 13 years of age. Other areas not thinned were subject to heavy mortality due to "an interrelationship of natural competitive effects with a superimposed and dependent population of *Sirex noctilio*" (Jackson, 1955).

The variable condition of the growing stock at time of thinning is best described by Table 1, which sets out the simple average and extreme conditions as revealed by assessment plots that determined mean data for 20 different logging settings.

Topography is basically undulating, with slopes in excess of 15° generally only of local occurrence.

The logging machine was the 52 drawbar horsepower HD6 tractor series E, with blade, winch and rubber-tyred arch. Powersaw used was 620 I.E.L. Utilization was to a 4 in. top and tree length hauling to prepared landings was the method of operation. Subsequent cutting to length and loading are beyond the terms of this discussion. Tree felling and tractor hauling were at all times in reasonable synchronization — *i.e.*, felling and hauling were not treated as independent operations.

TIME STUDIES

In 1964, T. W. Johnson, Work Study Officer, Rotorua, carried out detailed time studies in order to provide a system of preassessing work levels as a basis of a production bonus scheme. Standard time study procedure was adopted. This involves breaking down the total operation or work cycle into conveniently small phases of the job so that these "elements" can then be timed separately.

---

*Senior Work Study Officer, N.Z. Forest Service. Wellington.

TABLE 1

| Sample of Setting | Stems Per Acre | | | | | Total Gross cu. ft per Acre | Net Thin cu. ft per Acre | Net cu. ft per Merch. Thinned Tree |
	Total	Crop	Normal Thinnings	Malform Thinnings	Dead and Non-Merch.			
Lowest	158	48	53	3	6	8,250	3,320	34.1
Overall Average	241	62	81	25	73	10,140	4,360	41.5
Highest	326	76	107	49	137	13,720	6,070	51.4

TABLE 2

| Gang Strength | Topography | Base | Haul Distance | Net Merch. Tree Vol. | Thinned s.p.a. | | |
					Normal	Malform	Non-merch.
3	Flat –5°	1986	— 41.19	+ 23.11	+ 3.29	+ 2.85	— 2.59
3	Down 5–15°	1761	— 46.10	+ 23.65	+ 2.77	+ 2.43	— 2.15
3	Up 5–15°	1949	— 62.09	+ 21.15	+ 2.24	+ 2.15	— 1.81
4	Flat –5°	3108	— 111.01	+ 26.09	+ 2.63	+ 2.37	— 2.55
4	Down 5–15°	2948	— 109.33	+ 21.34	+ 1.15	+ 1.01	— 1.37
4	Up 5–15°	3042	— 120.84	+ 17.60	+ 1.01	+ 0.92	— 1.11

Thus a complete "library" of component times is derived for each part of the work and condition encountered. Some examples are:

(1) Walk with saw, flat ground, s.p.a. 200 — 0.29 min/tree

(2) Fell 10 in. d.b.h. merch. tree — 0.63 min
Fell 19 in. d.b.h. merch. tree — 2.49 min

(3) Cut sloven — 0.31 min

(4) Malform cut, up to 12 in. d.b.h. — 0.33 min

(5) Strop logs, slope 15°, butt hauling — 0.58 min

(6) Tractor travel unloaded, downhill to 10° — 0.19 min/chain

(7) Tractor breakout, flat, top haul — 0.72 min/tree

(8) Tractor driver unstrop at landing, unassisted — 0.25 min/tree

These are known as standard times and in all cases, throughout this paper, are quoted at 100 on the British Standard rating scale.

Use of Time Standards

The application of elemental time standards to any given logging setting is possible following a detailed field assessment. This is along normal mensurational lines and includes the determination of average hauling distance, topographical features and other factors which the initial time studies indicated had a bearing on job difficulty. Once this assessment has been carried out it is possible to calculate the duration of the average tractor cycle time to deliver a haul of a known average cubic capacity to the landing. This is because the assessment has enabled determination of the frequency with which such elements as felling, walking, and breaking-out must be carried out in order to produce a known average haul quantity. The calculation of this cycle time must take into account the precise degree of synchronization of the tractor and the bushmen as well as those contingency and rest allowances which normally make up part of the work day.

An example of this work content calculation, subsequent to the field assessment, is set out in Appendix 1.

Accuracy of Time Standards

The realism of the original time studies was demonstrated by the fact that, coupled with the introduction of a bonus scheme, this work measurement resulted in an initial boost in gang day output of 40%. The output levels so established have been maintained ever since.

The accuracy of the individual elemental standard times has been substantiated by over three years' successful bonus scheme administration. Apart from supervision factors, this success has been due to the ability to correctly preassess and maintain relativity in work output requirements which, in terms of cu. ft, may vary from setting to setting by as much as 25% because of changing combinations of variables.

193

Although statistical proof of the validity of the original studies is not available, it is maintained that the passage of time has clearly established the reliability of the data for the purpose for which it is being used.

CALCULATION OF DETAILED WORK VALUE

There are two main disadvantages to the system shown in Appendix 1 of calculating effect of such a multiplicity of variables. They are:

(1) The method is rather tedious and complicated, resulting in restricted use of the initial time study results.

(2) The simple effect of any one variable such as tree size or topography cannot be readily isolated and recognized.

In an endeavour to overcome these disadvantages, the data from 20 actual field assessments of Rotoehu logging thinning areas were examined.

Whilst the available information provided a sufficient range in tree stock conditions, other variables such as gang strength, topography and hauling distance were not strongly enough represented for satisfactory analysis. Accordingly each of the 20 sets of basic information was re-calculated 24 times using simulated circumstances allowing for two conditions of gang strength (3 and 4 men), four average hauling distances (6, 8, 10, and 12 chains), and three conditions of topography (flat to 5°, downhill 5 to 15°, and uphill 5 to 15°). There were then 480 different work content levels available for thorough analysis, each one of these being derived in a manner similar to that shown in Appendix 1.

These data were then subjected to linear regression analysis using a standard statistical formula. Such a linear model examines the variance of the daily production levels as measured by the sums of squares of the outputs about their mean. Variations are then accounted for in terms of the variables present and a value for each such variable is ascertained. The result for any combination of variables analysed can then be expressed in equation form.

The final stepwise regression analysis was programmed by staff of the Biometrics Section of the Forest Research Institute, Rotorua, and processed on the D.S.I.R. Elliott 503 computer.

Results of Linear Regression Analysis

Because of the difficulty of expressing two of the variables (gang strength and topography) in a suitable quantitative form, a single equation was not developed. The results are therefore expressed in the coefficients of six equations which are set out in Table 2.

The use of the values in Table 2 can be illustrated by calculating a daily work content level adopting the same variables as set out in Appendix 1 — i.e., a four-man gang; topography flat to 5°; 8 chain average haul; net tree volume 42.9 cu. ft; thinnings — normal 80, malform 25, and non-merchantable 23 s.p.a., respectively.

Selecting the appropriate values (fourth set of coefficients) the equation then is:

$3,108 - (8 \times 111.01) + (42.9 \times 26.09) + (80 \times 2.63)$
$+ (25 \times 2.37) - (23 \times 2.55)$

$= 3,550$ cu. ft (expected daily output).

The expected output calculated in the original manner as shown in Appendix 1 is 3,572 cu. ft, the equation result being 22 cu. ft (0.6%) less.

In order to check the estimates of the regression analysis against the original system, the work content levels arising from the initial 20 sets of stand data were calculated by both methods and compared. This showed that the confidence limits of the new system as against the original, are ±2.5% at the 95% level.
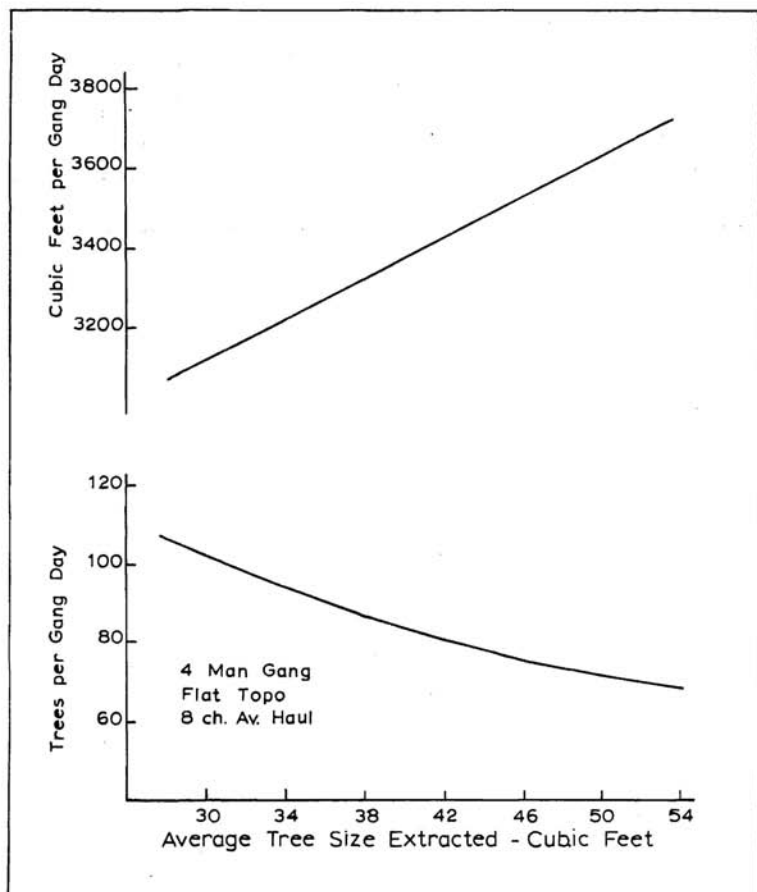

FIG. 1: *As the piece size increases, two effects are apparent; gang day cubic output increases while the daily output of pieces decreases.*

In practical terms this means that the likely variation between the two methods, in any one instance, will not generally amount to a greater cubic volume than would be contained in two trees per day. The mean variance was in fact only 0.25%.

PRACTICAL INTERPRETATION OF THE LINEAR MODELS

Having now the capability quickly to assess work levels under different simulated conditions, it is possible to take a close look at the effect of any one variable. What would previously have been a most laborious exercise is accomplished in a fraction of the time and some of the basic causes of variation in logging productivity can be clarified.

In Figs. 1 to 5, the stocking figures are kept constant at: normal thinnings 80, malform thinnings 25, and non-merchantable thinnings 65 s.p.a., respectively.

(1) Figure 1 shows the effect on daily production of the variation in piece size only. Piece size in this instance is represented by net merchantable tree volume. In this situation the trend revealed is that an increase in piece size of 5 cu. ft results in a daily increase in production of 130 cu. ft and at the same time a decrease in pieces produced of 7.75 trees per day.
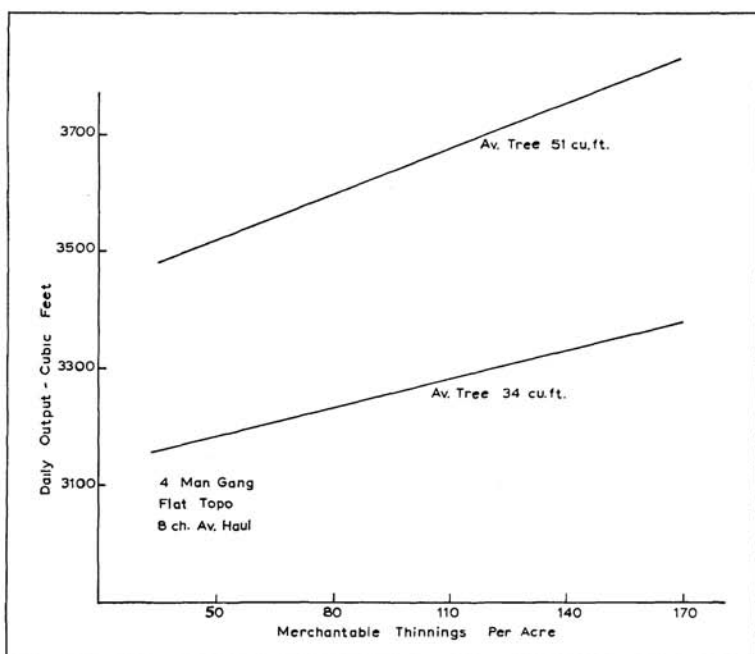

FIG. 2: *Two regression lines, representing extremes of average tree size, illustrate the effect of the number of cull stems per acre on daily cubic output.*

196

On the Rotoehu forest the actual range in tree size encountered is from 34.1 cu. ft to 51.4 cu. ft, which gives estimated daily output levels of 3,210 cu. ft and 3,660 cu. ft. This is a range of 450 cu. ft or 14% above the lowest level.

(2) The effect of number of merchantable stems per acre is relatively minor over the range experienced. This is shown in Fig. 2. For the largest tree size the increase in output is only 26 cu. ft for each additional 10 trees per acre and 16 cu. ft for the smallest average tree.

What Fig. 2 does highlight is the fact than an increase in volume per acre is not necessarily directly related to an increase in logging productivity. It is the combination of piece size and s.p.a. which is significant. For example, where the volume per acre of 3,060 cu. ft is composed of 60 stems averaging 51 cu. ft, the daily output would be 3,540 cu. ft. On the other hand, a volume per acre of 4,080 cu. ft composed of 120 stems averaging 34 cu. ft would result in an estimated output of only 3,300 cu. ft.
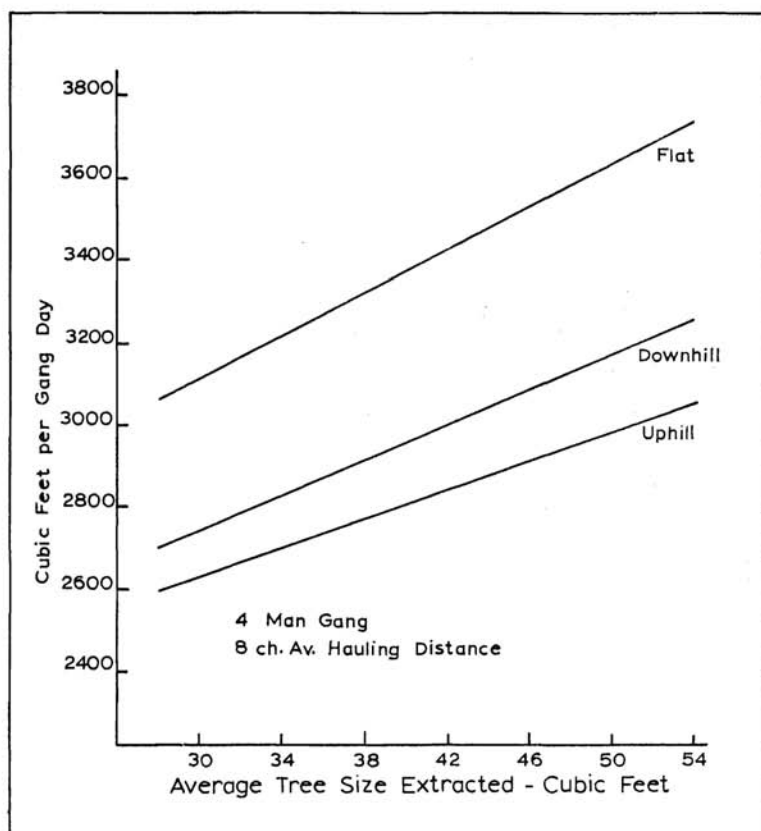

FIG. 3: *Gang day production as affected by average tree size extracted, for three different categories of topography.*

The extremes experienced in thinning volume per acre at Rotoehu have been 3,320 and 6,070 cu. ft. This composite factor has given a range in daily outputs from 3,251 cu. ft to 3,757 cu. ft — *i.e.*, 506 cu. ft or 16% above the lowest figure.

(3) Production as affected by topography is shown in Fig. 3. The regression lines are not parallel, indicating a greater effect with the larger piece sizes — *i.e.*, with an average tree of 30 cu. ft the daily production drops by 370 cu. ft for downhill and 480 cu. ft for uphill hauling, by comparison with flat conditions. With an average tree of 50 cu. ft the corresponding figures are 460 and 650 cu. ft, respectively.

By comparison with the findings in paragraph (1), it is apparent that, with a 50 cu. ft piece size, a change in topography from flat to downhill hauling causes a drop in production equivalent to that resulting from a reduction in piece size of 18 cu. ft. Similarly, a change from flat to uphill hauling causes a production drop equivalent to reducing the piece size by 25 cu. ft or in the latter case it could be said that uphill hauling results in a loss of production similar to halving the piece size.

Owing to the variable nature of the topography at Rotoehu in any one logging setting, the average effect of this factor will always be less than the extremes outlined above.

(4) The three regression lines in Fig. 4 show the effect on production of hauling distance for the three conditions of topography. For a four-man gang, each additional chain on to the average hauling distance reduces the estimated daily production by 111, 109 and 120 cu. ft for flat, downhill and uphill conditions, respectively.

Where the average piece size is 35 cu. ft it is apparent, from Figs. 1, 3 and 4, that the following three situations all reduce the daily production by 390 cu. ft:

(a) A drop in average tree size of 15 cu. ft.

(b) A change in hauling conditions from flat to downhill slopes.

(c) An additional 3.5 chains on to the average hauling distance.

(5) As illustrated in Fig. 5, the effect of increased hauling distance is to reduce the gang size required to keep the logging machine fully occupied. In a four-man gang, one member becomes completely redundant at 16½ chains for flat conditions and just under 15 chains for uphill hauling. However, the ultimate in productivity (as determined by unit cost) will be achieved by dropping the fourth man considerably before the two points just mentioned. This can be illustrated using very simple direct costs of, say, $20 per day for the tractor and $10 per day for each man. Thus a three-man gang direct cost would be $50 per day and $60 for a four-man gang. From the graph of flat conditions, the output at the point of meeting of the two lines is 2,300 cu. ft. Therefore, the direct unit cost for a three-man gang would be:

$50/2,300 = 2.17 cents per cu. ft

and the output by a four-man gang to give a similar cost would be:

$60/2.17 = 2,765 cu. ft.

198

Then from the four-man regression line it can be seen that a 12 chain average haul would be the optimum compared with 16½ chains for the three-man gang. This is, of course, an over-simplification as the logger would need to take into account the effect on roading cost and the movement in indirect and overhead costs. However, the principle as proclaimed is valid.

(6) The combined effect of a number of variables can, of course, be very considerable. The data so assembled can, in fact, be used
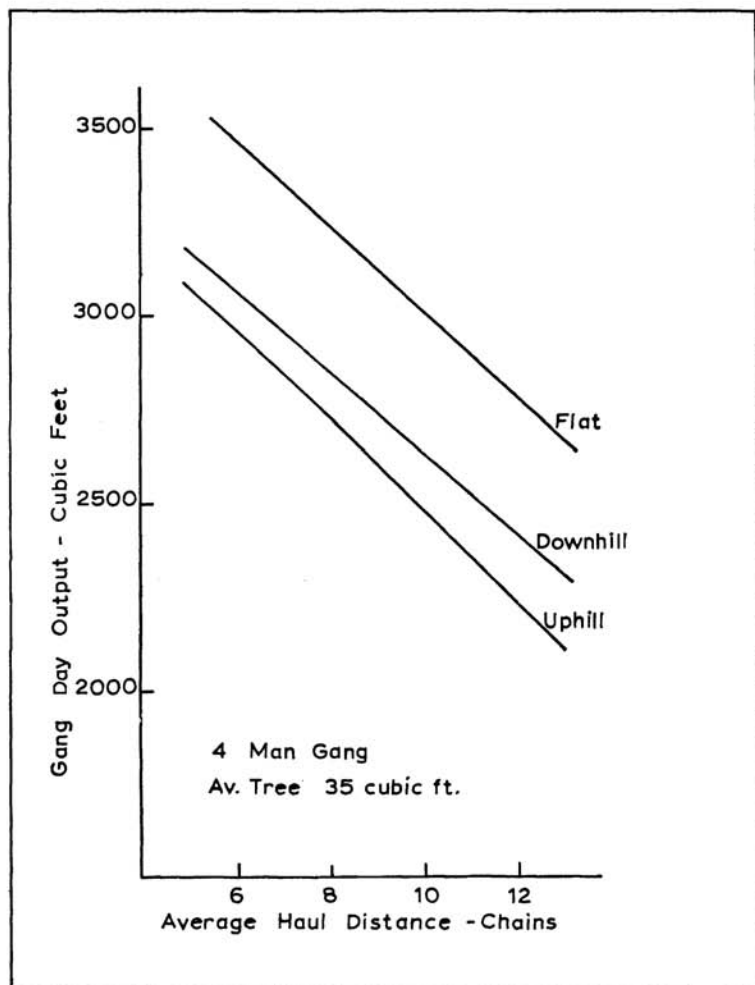

FIG. 4: *Gang day production as affected by average hauling distance, for three categories of topography.*
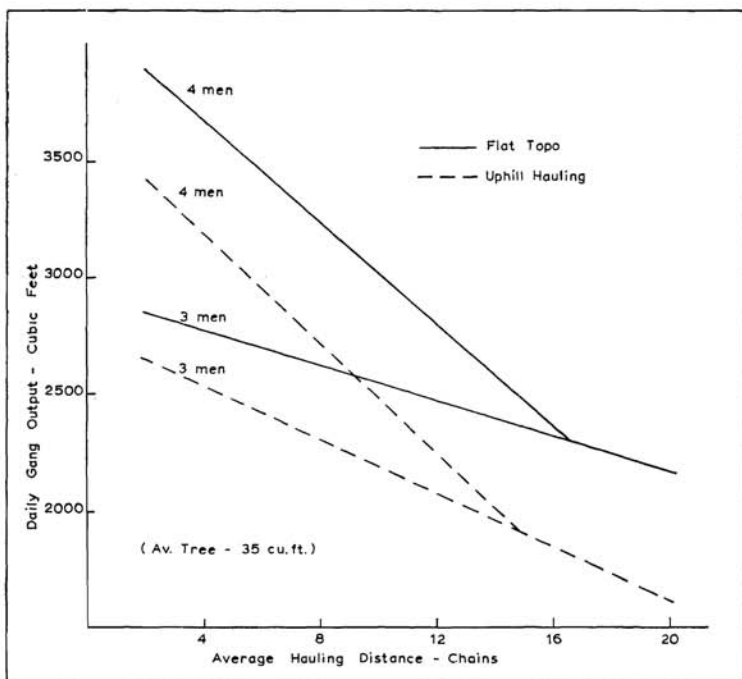
FIG. 5: *Gang day production as affected by average hauling distance and a variable gang strength, for two categories of topography. The fourth gang member eventually becomes redundant as dictated by an increasing hauling distance.*

to predict a range of output from at least 2,040 cu. ft to 3,870 cu. ft. Assuming no variation in stocking density, this range could arise from two credible extremes:

(a) At the low point, a three-man gang, uphill hauling, an average piece size of 34 cu. ft an average distance of 12 chains, and

(b) At the high point, a four-man gang, on flat conditions, with a piece size of 51 cu. ft and an average haul of 6 chains.

This then provides quite a potent means of predetermining the consequences of alternative management decisions.

CONCLUSION

It is quite false generally to categorize logging thinning variables into any order of difficulty unless qualified by a statement of the common range of overall conditions encountered. The relative trends observed here may not be valid where the range of piece size is, say, from 10 to 20 cu. ft, slopes are consistently in excess of 15° or where rubber-tyred skidders are in use.

It is not claimed that the equation values discussed here are absolute but it is maintained that such a method of analysis should provide a valuable aid in logging planning and perhaps eventually assist with the development of silvicultural regimes.

ACKNOWLEDGEMENT

I am indebted to E. O. Griffiths for his assistance and particularly his initial development of the linear model as set out in Econometric Methods by J. Johnston of the University of Manchester.

REFERENCE

Jackson, D. S., 1955. The *Pinus radiata/Sirex noctilio* Relationship at Rotoehu Forest. *N.Z. J. For., 7 (2)*: 26–41.
Johnson, T. W., 1964. Unpublished N.Z. Forest Service report.

LOGGING THINNING WORK VALUE CALCULATION

Tractor Cycle	min	*Bush Cycle*		min
Haul loaded 8 ch × 0.25	2.24	Fell trees	2.98 × 1.48 × 2	8.82
Haul return 8 ch × 0.23	1.84	Walk to fell	2.98 × 0.37 × 2	2.21
Position tractor in bush	0.85	Cut slovens	2.47 × 0.31	0.77
Return to edge of landing		Head off	2.63 × 0.31	0.82
and clear rubbish	1.19	Walk to H.O.	2.63 × 0.37	0.97
Run loaded in landing	0.60	Malcuts	0.47 × 0.58	0.27
Wait loader	0.17			——
Drop at landing 2.56 × 0.25	0.64			13.86
Put up strops	1.15	+ Cont. 10.5%		15.32
	——			——
	8.68			
	——	Trimming 9.80 mins/100 cu. ft		10.29
		Prestrop logs 2.63 × 0.50		
		+ 3.5%		1.36
Release strops in bush	0.29	Release strops in bush		0.29
Breakout 2.56 × 0.55	1.41	Breakout 2.56 × 0.55		1.41
	——			——
	1.70			3.06

Cycle	*Min.*	*Max.*	*Av.*		
Tractor + —				Total bush time	28.67
(4.08)	6.30	14.46	10.38		
Bush	9.56	9.56			
Interference	3.26	4.90			
	IO	IM			
Interference					
IO^2		3.26^2			

2 (IO + IM = 2 (3.26 + 4.90)		Av. for 3 bushmen	9.56
= 0.65		Actual work duties:	
Basic tractor cycle	11.03	Total P/saw time	9.22
+ Tractor cont. 6.4%	11.74	Other bush time	9.16
+ Rest allowance 15.5%	13.56	Trimming time	10.29
+ Minor cont. on basic			——
time 5%	0.55		28.67
	——		
Total tractor cycle	14.11		

If 105 cu. ft (average haul size) of logs are produced every 14.11 minutes then 8 hour daily production will be:

480/14.11 × 105/1 = 3,572 cu. ft

In the above example, a four-man gang is operating in a setting wnere the average hauling distance is 8 chains and the slopes do not generally exceed 5°. The assessment has ascertained that the crop s.p.a. is 68 and thinning s.p.a. 148, made up of good form thinnings 80, malform merchantable thinnings 25 and non-merchantable 23. Average net volume of merchantable thinnings is 42.9 cu. ft. Gross volume per acre is 9,930 cu. ft and net volume thinned is 4,510 cu. ft.