A HIGHLY MECHANISED HARVESTING SYSTEM IN NEW ZEALAND

C. J. TERLESK and K. WALKER

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

(Received for publication 10 July 1981; revision 16 November 1981)

ABSTRACT

A highly mechanised harvesting system was studied in 1976 to establish likely production rates. It was estimated that the system had the potential to produce 300 m^3/day at a direct cost on truck of NZ$4.33/$m^3$ (compared with NZ$6.15/$m^3$ from a motor-manual operation) but monitoring of the system disclosed a much lower production level than anticipated, probably because of lower utilisation than expected. In a second study utilisation of the feller-buncher was only 42%, and the system production level 160 m^3/day (estimated cost NZ$12.50/$m^3$ on truck). When the system was studied again for 5 weeks in January-February 1979, feller-buncher utilisation had improved to 67%. As this machine was the lead machine in the system, production improved significantly and the cost per cubic metre was competitive with costs from a motor-manual operation.

Because of the need to carry out major overhauls of the machines and the availability of a more abundant supply of labour for motor-manual operations, the system was closed down in 1979.

INTRODUCTION

The highly mechanised system under review made its appearance in New Zealand in early 1976. It was developed to harvest small piece-size *Pinus ponderosa* Laws. on easy terrain in Kaingaroa State Forest. Extensive areas of Kaingaroa Forest, particularly on the harder sites, were planted in *P. ponderosa* in the 1920s and 1930s, but the species proved a poor choice. Growth rates were low compared to *P. radiata* D. Don, and current forest policy is to clearfell the *P. ponderosa* stands and replace with the economically more attractive *P. radiata.*

Detailed work measurement of the highly mechanised system was undertaken in three compartments (Table 1); temporary plots were laid out in each compartment, and a volume table was constructed for each from sectional measurement of 50 trees. This approach ensures an accurate estimate of piece size. In a typical sample of 35 trees in a temporary plot the mean d.b.h. was 22.4 cm, the mean tree volume was 0.22 m^3, the mean length to 7 cm small-end diameter was 11.9 m, and there were 22 whorls to the same point. There were on average 100 branches per tree; they were persistent and presented a formidable delimbing task.

TABLE 1—Details of the **Pinus ponderosa** stands used in the mechanised harvesting study

	Cpt 670, planted 1934	Cpt 667, planted 1934	Cpt 680, planted 1935
Total stems/ha	1245 (range 840–1581)	1270 (range 741–1532)	1420 (range 117–1775)
Live stems/ha	993 (range 642–1359)	960 (range 618–1359)	1135 (range 950–1400)
Dead stems/ha	252 (range 74–494	310 (range 125–568)	285 (range 150–525)
Mean volume merchantable stems to 7 cm s.e.d. (m^3)	0.167	0.206	0.164
Merchantable volume to 7 cm top (m^3/ha)	166	198	186
Mean d.b.h. (cm)	19.0 (s.d. ± 6.42)	20.7 (s.d. ± 6.35)	21.1 (s.d. ± 6.5)
Mean crop height (m)	15.3	—	14.0
Live stem basal area (m^2/ha)	28.2	32.2	39.7
Terrain	Generally flat with some impeding vegetation	Generally flat and covered by light to heavy monoao and manuka scrub	Generally flat and covered by light to moderate monoao and manuka scrub

STUDIES OF THE HIGHLY MECHANISED SYSTEM

A Drott 40LC feller-buncher, a Vulcan chain-flail delimber mounted on a rubber-tyred skidder, two grapple skidders, and a rubber-tyred loader made up the system. One power-saw operator was positioned on the landing to carry out a final trimming and cutting to length. The operation was costed to the point where the prepared trees were stacked in piles on the landing. The second phase of the operation, involving a second loader and a company fleet of Kenworth trucks supported by independent contractors was not studied in depth.

The feller-buncher moved in a continuous clock-wise direction around the block preceding the chain-flail delimber. The delimber was followed by the two grapple skidders which extracted to the landing over a mean haul distance of 100 m. Roads were spaced 400 m apart and parallel to each other (where possible), and landings were formed at 400-m intervals along the roads. Roads and landings were not metalled, but the porous nature of the volcanic pumice ensured good drainage and reasonable access throughout all seasons.

All operators studied had at least 3 months' experience with the machines making up the system. The feller-buncher operator's production had risen from 52 trees per productive machine hour when he began to 110 trees after 3 months' experience, and the graphing of production rates over time indicated that this rate could be maintained. The ceiling performance was estimated at 130 trees/hour.

The New Zealand experience with highly mechanised systems is mainly in clear-felling operations; however, the constraints discussed here are almost certain to apply in production thinning operations.

The results of the three work-measurement exercises are outlined below.

Estimating Potential Productivity

Prior to the major work-measurement exercise a short pilot study indicated the need to rationalise the work methods to improve machine flow and reduce interference, and many of the suggestions were adopted by the company.

Analysis of the collected data showed that the system using an improved work method was generally in balance (Table 2). The analysis was based on the following assumptions:

(a) A 7-hour productive day in a 9.5-hour shift day (73% utilisation);

(b) The grapple skidder could deliver to the landing all the material produced by the other two machines in the system through a reduction in time spent on the landing (35% of the production cycle);

(c) All operators had at least 3 months' experience.

Based on double shifts for the feller-buncher and the chain-flail and single shifts for two grapple skidders, it was estimated that the system had the potential to produce *c.* 300 m^3/day. The capital cost of the system was NZ$390,000 (in 1976) which resulted in a daily (double shift) cost of NZ$1300, including labour. For the predicted production of 300 m^3 the expected direct cost on truck was NZ$4.33/$m^3$, compared to NZ$6.15/m^3 for a motor-manual operation with a daily production of 40 m^3 per 8-hour shift, a daily

TABLE 2—Production rates for the highly mechanised system in 1976

Machine	Production		
	p.m.h./day	m^3/p.m.h.	m^3/day
Feller-buncher	14	22.0	308
Chain-flail delimber	14	22.1	310
Grapple skidders* (Clark Ranger 667)	14	20.7	290

* Two machines, single shift

system cost of NZ$246, and 75% utilisation assumed, i.e., 6 productive hours in the scheduled 8 hours. The highly mechanised system thus had a cost advantage over traditional motor-manual operations, but continued monitoring showed that it was not achieving the predicted level of production.

Analysis of Availability and Utilisation

Machine availability and utilisation were studied over both day and night shifts for a 5-week period, commencing in November 1976. The mean tree size during the course of this study was 0.206 m^3 – 23% larger than in the previous study.

"Availability" is defined as the proportion of the total shift that the machine is mechanically available to work, i.e., when it is not waiting for, or undergoing, repairs or servicing and maintenance.

$$\text{Availability} = \frac{\text{Total shift time} - \text{Mechanical delay time}}{\text{Total shift time}} \times \frac{100}{1}$$

"Utilisation" is defined as the proportion of the total shift that the machine does productive work.

$$\text{Utilisation} = \frac{\text{Total shift} - \text{(Operational, social, \& mechanical delays)}}{\text{Total shift time}} \times \frac{100}{1}$$

Availability and utilisation were determined for the four machines (Table 3) but there is some doubt about the reliability of the night shift data because of the low level of sampling. The time distribution of the Drott Feller-Buncher is analysed in Table 4. Forty percent of the mechanical delay time was spent on repairs to the ancillary equipment of the machine, i.e., the boom and felling head.

TABLE 3—Availability and utilisation in 1976

Machine	Availability (%)		Utilisation (%)	
	Day shift	Night shift	Day shift	Night shift
Feller-buncher	52.0	62.0	42.3	41.5
Chain-flail delimber	67.3	87.7	44.1	62.3
Grapple skidder 1	74.1	—	38.6	—
Grapple skidder 2	71.3	—	32.4	—

TABLE 4—Time distribution for the feller-buncher in 1976

	Activity	Day shift*		Night shift†	
		Time (%)	S.E.	Time (%)	S.E.
Mechanical delay time	Wait repairs (ancillary equip)	14.0	2.8	0	—
	Wait repairs (prime mover)	0	—	28.6	5.4
	Active repairs (ancillary equip)	12.8	2.7	0	—
	Active repairs (prime mover)	0.7	0.7	6.6	2.9
	Off-site repairs (ancillary equip)	12.8	2.8	0	—
	Off-site repairs (prime mover)	0	—	0	—
	Servicing and maintenance	7.7	2.2	2.8	1.8
Operational delay time	Wait for work	1.7	1.1	0	—
	Other-on-site	2.0	1.2	3.8	2.2
	Other-off-site	0	—	0	—
Social delay time	Personal time	6.0	1.8	16.7	4.4
Mechanical availability		52.0	4.1	62.0	5.7
Utilisation		42.3	4.1	41.5	5.8

* Based on 586 observations during 13 day-shifts selected randomly within a 5-week peroid; mean shift length 10.14 hours.

† Based on 287 observations during three night-shifts selected randomly within the same period; mean shift length 10.18 hours.

Machine utilisation levels observed in this study were much lower than those assumed in the first exercise, which in part explains why production was lower than predicted. Since breakdowns and other stoppages do not occur simultaneously in each machine, the result is a very low figure for system utilisation and high unit costs of production. At a production level of 160 m^3/day and daily operating costs of NZ$1300, the cost escalated to NZ$12.50/$m^3$ which compared unfavourably with that for the conventional motor-manual approach.

Analysis of the study data showed that, in addition to the low availability and utilisation percentages (Table 3), the feller-buncher was felling only 87 trees/hour (18 m^3/p.m.h.), not 110 as in the earlier study. A combination of low productive machine hours per shift and a lower than expected production rate materially affected the production of the entire system (Fig. 1). The feller-buncher spent a small proportion of its time (1.7%) waiting for work but the chain-flail, which is next in the process line, spent 8.1%. The grapple skidders, which are largely dependent on the two preceding machines, spent 21.8% of the day waiting for work. It is, therefore, reasonable to assume that a production increase from the feller-buncher would have led to a production increase from the system.

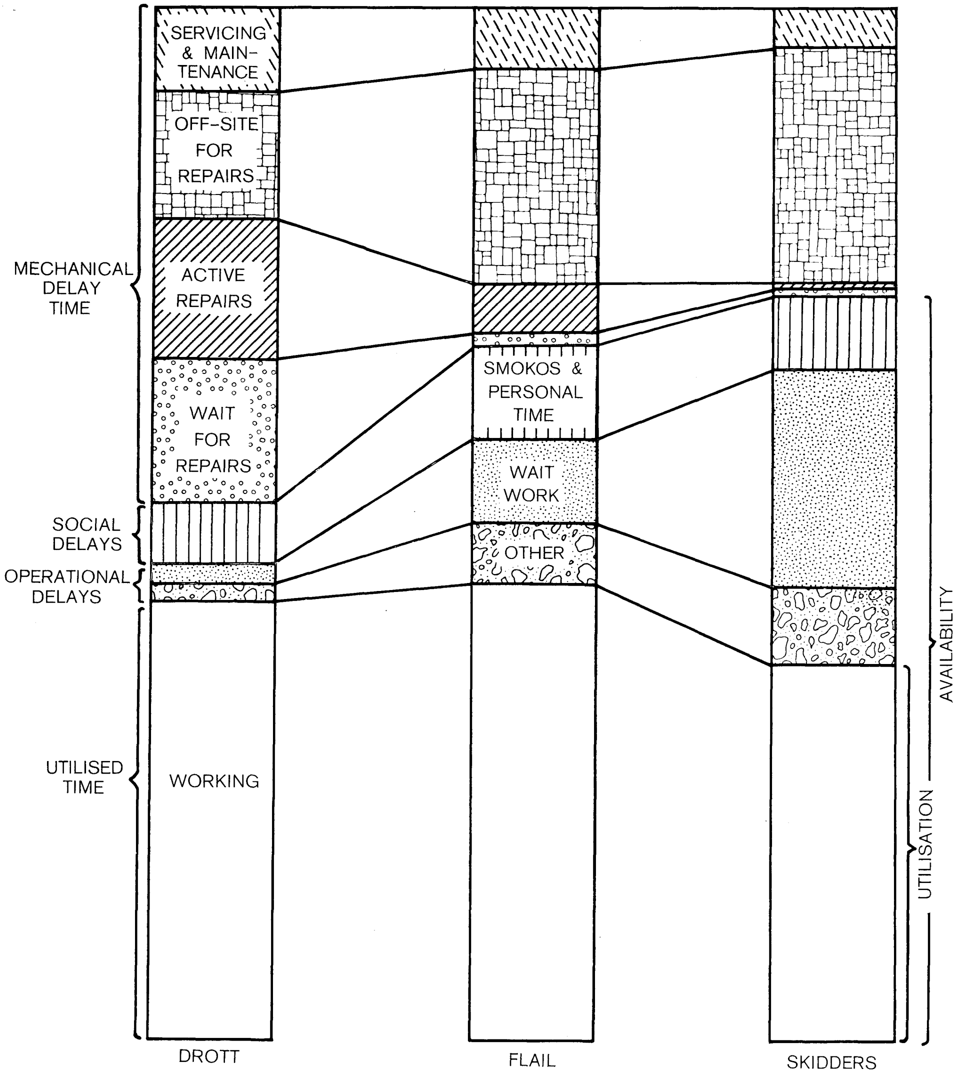

FIG. 1—Machine time distribution in 1976 - day shift

In order to achieve this, the owner company undertook a review of the management and servicing functions to improve repair facilities and to allow supervisory staff more time for both planning and supervision. These measures, in conjunction with further operator training, were aimed at consolidating the first year's experience and acting on some of the results of the detailed work measurement exercises.

Validation Study

The system was again studied for 5 weeks in January-February 1979, about 3 years after its introduction. At this time there had been a considerable improvement in machine availability and utilisation levels (Table 5) compared to the second study. The production rate per machine hour was also high, the feller-buncher achieving 135 trees/hour (Table 6). In this study it was the chain-flail delimber, with a production rate of 122 trees/p.m.h., which held down the over-all production level. Mechanical availability and utilisation levels for the feller-buncher had improved (Table 7) in comparison to those in the second study (Table 4). These improvements are considered to be a direct result of the development of a comprehensive maintenance and servicing policy by the owner company.

TABLE 5—Availability and utilisation in 1979

Machine	Availability (%)		Utilisation (%)	
	Day shift	Night shift	Day shift	Night shift
Feller-buncher	80.1	78.5	66.8	64.7
Chain-flail delimber	75.4	63.8	61.9	51.3
Grapple skidder 1	86.4	—	64.0	—
Grapple skidder 2	79.9	—	53.9	—

TABLE 6—Productivity of the mechanised system in 1979

Machine	No. of trees prepared/ p.m.h.*	Volume/p.m.h. (m^3)
Feller-buncher	135	21.1
Chain-flail delimber	122	19.5
Grapple skidders (2)	140	22.4

* p.m.h. = productive machine hour

Figure 2 sets out the machine time distribution of the highly mechanised system in this study. The improved performance of the feller-buncher had removed the "waiting for work" component in the chain-flail cycle which in turn caused only a small wait element in the cycles of the grapple skidders.

Based on the data from this third study, the cost per cubic metre compared favourably with the costs generated by the conventional motor-manual system. This resulted from the dramatic improvements in the availability and utilisation and consequent improve-

TABLE 7—Time distribution for the feller-buncher in 1979

	Activity	Day shift*		Night shift†	
		Time (%)	S.E.	Time (%)	S.E.
Mechanical delay time	Wait repairs (ancillary equip)	2.8	1.2	11.0	2.3
	Wait repairs (prime mover)	3.4	1.4	0.1	0.2
	Active repairs (ancillary equip)	2.0	1.1	4.2	1.4
	Active repairs (prime mover)	4.5	1.6	0.9	0.7
	Off-site repairs (ancillary equip)	0	—	0	—
	Off-site repairs (prime mover)	0	—	0	—
	Servicing and maintenance	7.1	1.9	5.2	1.6
Operational delay time	Wait for work	0	—	0	—
	Other-on-site	5.7	1.7	4.7	1.5
	Other-off-site	0	—	0	—
Social delay time	Personal time	7.7	2.0	9.0	2.1
Mechanical availability		80.2	3.0	78.5	3.0
Utilisation		66.8	3.5	64.7	3.5

* Based on 704 observations during 11 day-shifts randomly selected within a 5-week period; mean shift length reduced to 8.5 hours through management reorganisation and operator overlap for shared maintenance tasks.

† Based on 763 observations during six night-shifts randomly selected within a 5-week period; mean shift length reduced to 8.5 hours.

ment in production rates. However, the provision of adequate, extensive servicing functions is a real cost and should be considered as an integral cost of setting up a highly mechanised operation.

Shortly after the completion of the third study, the need to replace or carry out major overhauls of the machines, together with a more abundant labour supply for motor-manual operations, led to a decision to close down the highly mechanised system.

ANALYSIS OF STUDIES

It is pertinent at this juncture to examine the structures of both the highly mechanised and motor-manual systems in order to better appreciate the factors that magnify or diminish the effects of availability and utilisation percentages and rates of production.

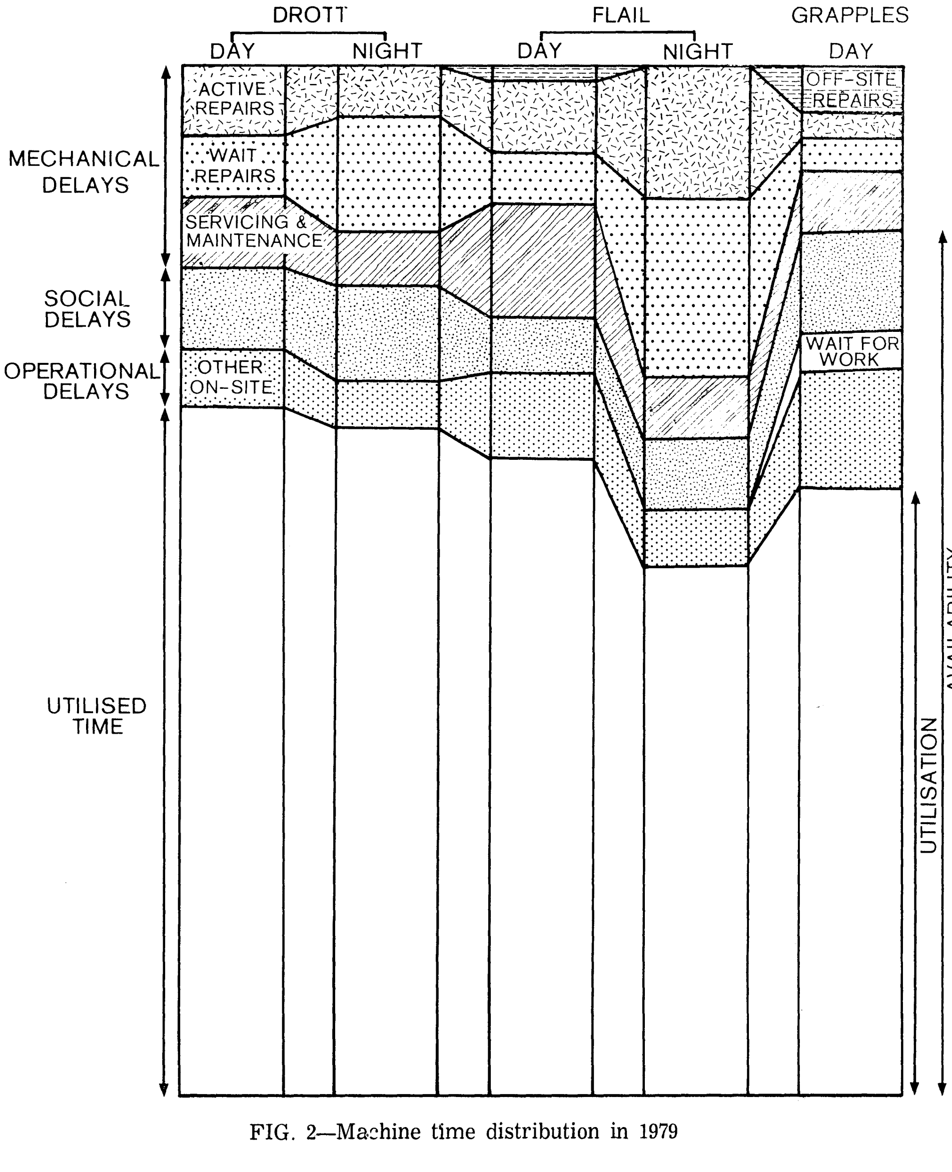

FIG. 2—Machine time distribution in 1979

Figure 3 sets out the operational configurations of a highly mechanised harvesting system working single and double shifts and the configuration of five motor-manual systems operating on a single shift basis. Five motor-manual crews on single shift equate to the theoretical production level of one highly mechanised system on a double shift basis. The system diagrams show that the broad operational configuration of the highly mechanised system is predominantly vertical and linearly dependent (Fig. 3, A and B), while the configuration of parallel motor-manual systems is predominantly

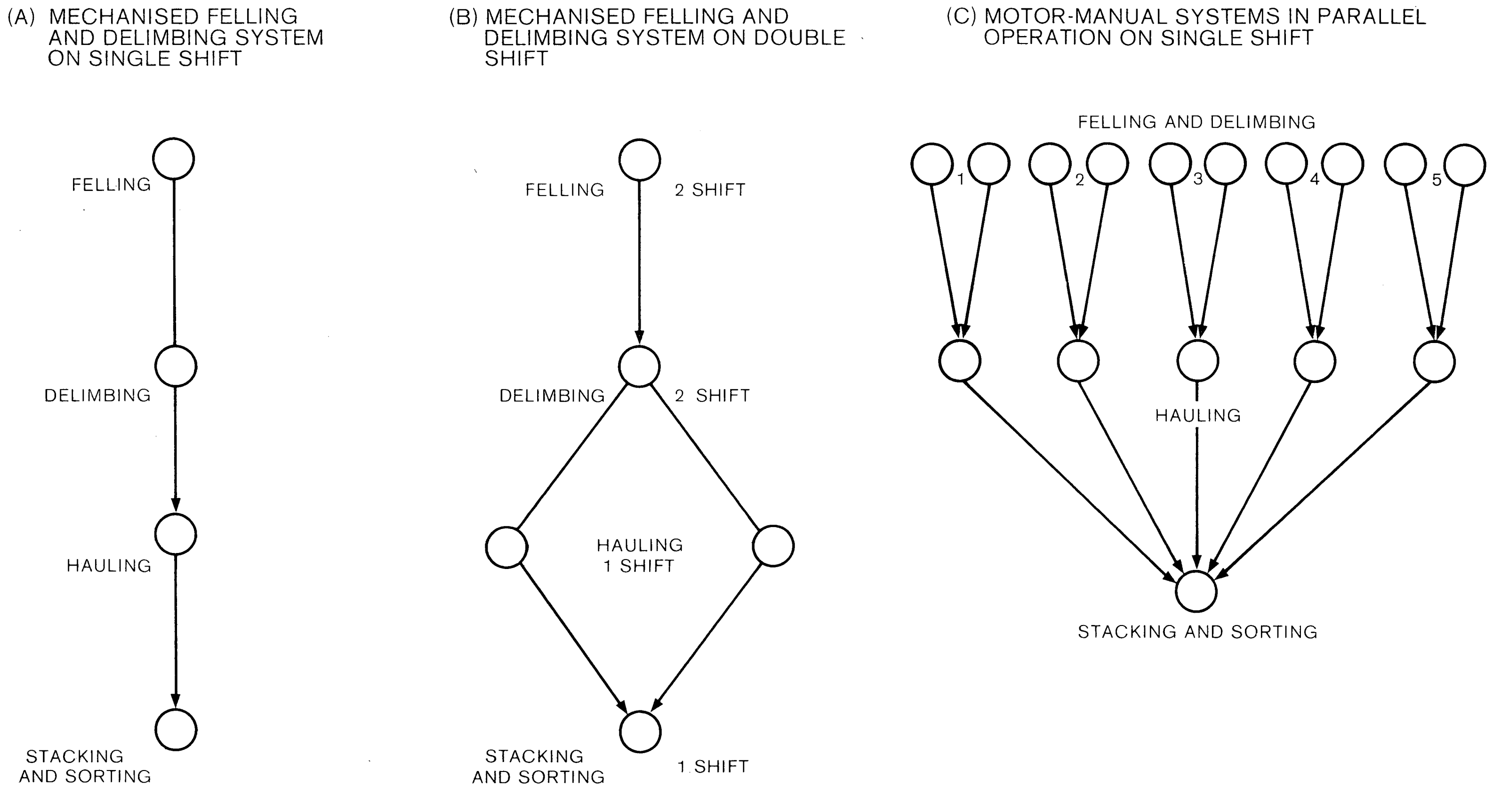

FIG. 3—Operational configurations of systems

horizontal and displays a high degree of linear independence (Fig. 3, C). The former configuration is usually more sensitive to interruption than the latter, and the latter tends to have greater flexibility under changing production levels.

This change is reflected in the comparable increase in the capital recovery element in Table 8, which also shows the strong interchange of capital and labour between the two main systems.

The differences between activities of a direct productive nature, materials handling (transport function), and servicing are not as pronounced as might be expected (Table 9), the change being mainly between direct production and materials handling where the pattern for the highly mechanised systems is the reverse of that for the motor-manual system.

TABLE 8—Breakdown of labour, machine operating, and capital recovery costs of systems*

	Mechanised double-shift system	Mechanised single-shift system	Motor-manual system
Original capital	$390,000	$280,000	$53,000
Daily cost (to nearest $10)	$1,240†	$720	$240
Labour (%)	24	27	47
Machine operating (%)	32	30	26
Capital (%)	44	43	27

* Analysis of costing for Tables 8, 9, and 10 available on request.
† Indirect administrative overheads omitted from this analysis.

TABLE 9—Breakdown of productive, material handling, and service activity costs of systems

	Mechanised double-shift system	Mechanised single-shift system	Motor-manual system
Original capital	$390,000	$280,000	$53,000
Daily cost (to nearest $10)	$1,300	$750	$250
Productive activity (%)	40	40	32
Materials handling* (%)	30	26	43
Servicing (%)	30	34	25

* Transport function

This, combined with the change in relationship between capital and labour (Table 8), suggests a cost trade-off between labour and capital which is counteracted by a converse trade-off between direct productive and materials handling activities. The effect of cost distribution changes on over-all costs is likely to be marginal, resulting in minimal variations in the comparative production costs of the two principal systems, viz, mechanised felling and motor-manual felling. This is particularly likely where, in addition, no appreciable change occurs between variable and fixed cost ratios.

The key, under these conditions, lies with the inter-unit flexibility of the multi-unit, motor-manual system over a wide range of production levels.

The variable contents of the systems remain comparable, ranging from 17% to 20% of daily costs (Table 10). This relatively low variable element indicates that for each system, effective operating time is a major determinant of unit costs of production. While the relationship between variable costs and fixed costs remains comparable between the systems, when fixed costs are broken down into interest charges and other fixed costs, it is apparent that the charge for interest in the mechanised system is much greater than that in the motor-manual system.

TABLE 10—Breakdown of the variable, fixed, and interest charge contents of system costs

	Mechanised double-shift system	Mechanised single-shift system	Motor-manual system
Original capital	$390,000	$280,000	$53,000
Daily cost (to nearest $10)	$1,300	$750	$250
Variable content (%)	20	17	18
Fixed content (%)	60	62	70
Interest charge content (%)	20	21	12

Effect of Changing Production Levels on the Three Systems

An earlier study (C. J. Terlesk unpubl. data) indicated that production for a single-unit motor-manual system, operating in conditions similar to those of the mechanised harvesting systems analysed, would range from 30 m^3 to 45 m^3 per 8-hour day. To cover this range, unit costs have been developed for a daily production of 25 m^3 to 50 m^3, but at the upper production limit excessive pressure would be placed on the system, and it is unlikely to be achievable in practice. For this reason the unit costs should be used only for determining the relative positions of the three systems. These restrictions apply equally to the resultant production costs of the mechanised harvesting system.

It is apparent that unit costs are influenced equally by production levels in each system (Fig. 4). This is because of the high degree of comparability in the ratio of variable cost to fixed cost content (Table 10), and indicates that the development of highly mechanised systems will not necessarily result in lower unit costs of production.

The inter-unit flexibility of the multi-unit motor-manual systems (Fig. 4, A1–6) gives an advantage over the mechanised systems (Fig. 4, B and C). At a production rate of less than 95 m^3/day, two or three motor-manual units are clearly more cost-effective than the highly mechanised system. Between 95 m^3 and 140 m^3, selection of either motor-manual or mechanised systems would rest on features other than cost of production since the cost differential between the two is minimal. Between 140 m^3 and 190 m^3/day, four to five motor-manual systems show some advantage over the mechanised system as at this point production falls between the single-shift and double-shift phases of the system. Over 190 m^3/day the choice of system is again unlikely to be affected by cost of production.

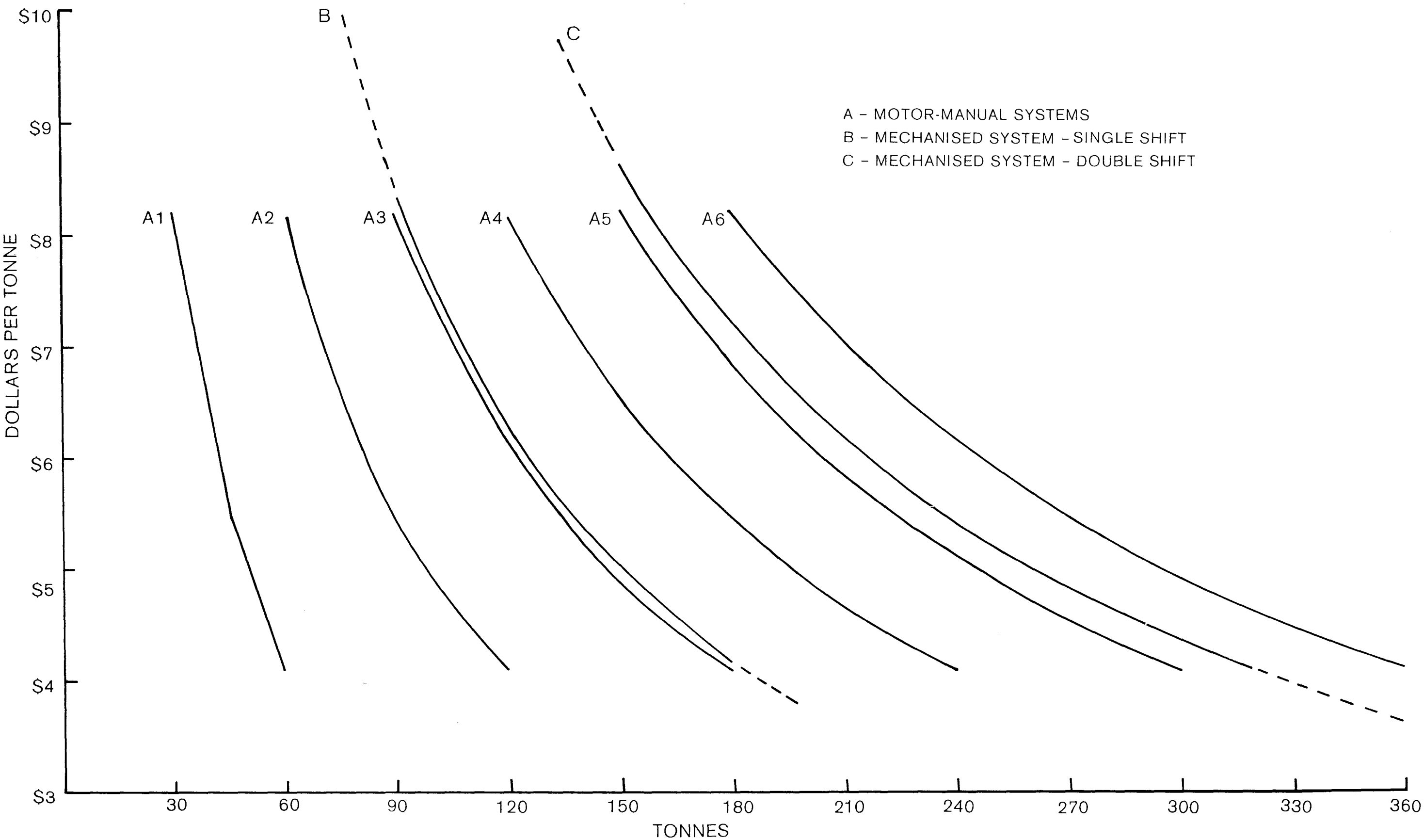

FIG. 4—Production cost relationship between single- and double-shift mechanised harvesting systems and a comparable series of motor-manual systems

CONCLUSIONS

Highly mechanised systems, because of their high capital cost and low variable cost content, require both high machine utilisation and high rates of production to make unit costs of production competitive. If high availability and utilisation levels are to be maintained, adequate repair and servicing facilities must be an integral part of the system. Management must be aware of the problems inherent in an expensive and closely integrated system and must make provision for informed supervision and the installation of an adequate monitoring system. To achieve high production levels, operators must receive appropriate training, they must be well motivated, and staff turnover must be minimised to ensure that high production levels are maintained. Increased repair and maintenance facilities, increased management activity, training programmes, and labour motivation are additional costs which should be included when comparisons are made with motor-manual operations.

Motor-manual operations, although requiring greater labour input, have some advantages that should not be lightly discounted. Operating as a parallel multi-unit system they offer a greater degree of flexibility due to the possibility of inter-unit adjustments. This flexibility extends to terrain and species changes and fluctuations in piece size, all important considerations in New Zealand where terrain changes occur frequently and often dramatically.

The disadvantages of the motor-manual systems are well known – e.g., labour recruitment problems, the inherent dangers of the operation, accidents with power saws, the effect of climate on worker productivity, and its effect on the cost of production.

These factors, together with the extent of the resource and demand for the product, must be carefully examined when systems are being considered. The New Zealand industry is currently opting for the motor-manual approach.

ACKNOWLEDGMENTS

Study originators, M. McConchie and G. Murphy of the FRI Harvesting Group, are cordially thanked for their contributions to this paper. Thanks are also due to the Carter Oji Kokusuku Pan Pacific Company Ltd for access to their operation and for the extensive assistance provided to the authors and the various study groups.