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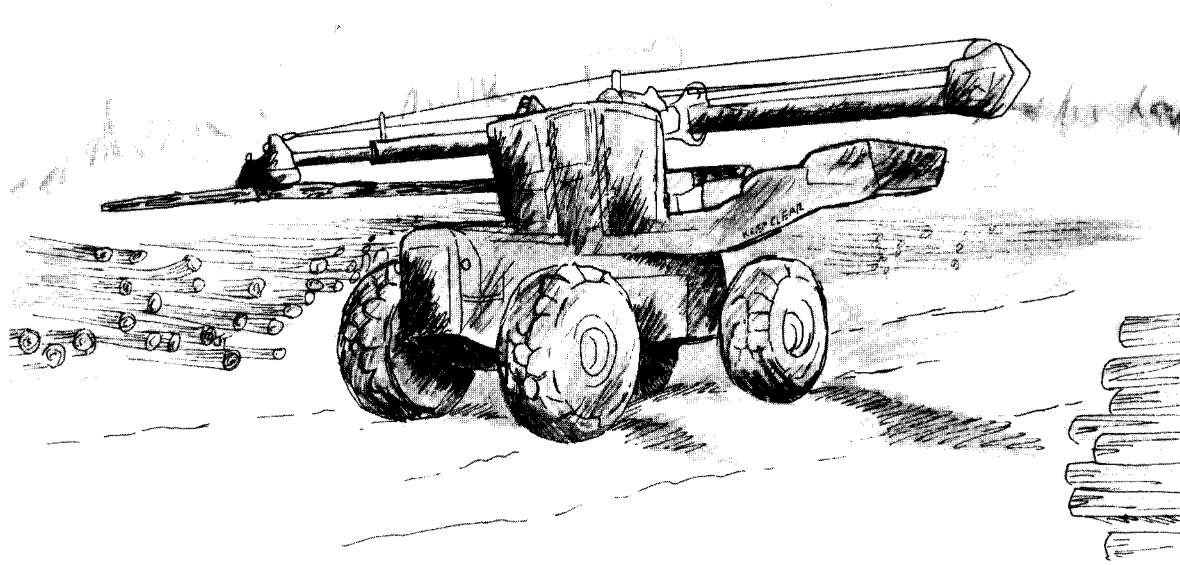
A CASE STUDY OF ROADSIDE LOGGING IN THE CENTRAL INTERIOR OF BRITISH COLUMBIA

A.J. MacDonald

December 1988



Technical Report

TR-87

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Summary

FERIC monitored all phases of a roadside logging system in one block of old-growth timber in the British Columbia Interior. The study objectives were to determine the productivity and cost of each logging phase, and monitor the interactions between phases.

The prime logging equipment consisted of a Caterpillar FB221 feller-buncher, a John Deere 740A grapple skidder, two Timberjack 90 processors, and a Caterpillar LL229 butt-and-top log loader. The total volume logged was 24 146 m^3, the piece average was 0.29 m^3, and the direct stump-to-truck logging cost was \$8.11/m^3. Road construction accounted for a further \$0.25/m^3 and bulldozer costs, to pull log trucks through muddy road sections, amounted to \$0.06/m^3. Costs were derived by FERIC and are not the actual costs incurred by the company or the contractor.

Study results showed that approximately 1.5 falling and processing hours were required for each skidding hour, and that about 1.5 skidding hours were required for each loading hour. Production by phase varied from 544 m^3 per 8-hour shift for the loader, to 240 m^3 for the TJ90 processors. Falling and processing each accounted for 33% of direct logging costs, while skidding, and loading each accounted for about 17%.

The utilization of machines ranged from 67% for one TJ90 processor to 92% for the LL229 loader. Major causes of delay were organizational delays and repair and service. Up to 10% of the skidder's and processors' total shifts and 7% of their time during production shifts was lost because of wait-for-wood delays when the FB221 feller-buncher was unable to fall sufficient trees for the other machines to maintain full production. A second feller-buncher was added and no further delays were caused by insufficient inventory.

The machines' repair requirements varied. The LL229 loader required the least time for repairs, at 2.5 hours per 100 productive machine hours (PMH), and one TJ90 processor required the most time for repair at 23.8 hours per 100 PMH. In general, the falling and processing attachments required the most repairs.

There was little variation in productivity per PMH between day and night shift. However, utilization on night shift was generally higher, so production per shift was higher. This was mainly because minor repairs were scheduled during the day and repair times per shift were 0.3-0.6 hours longer.

Sommaire

FERIC a assuré le suivi technique de toutes les phases d'une exploitation par système en bordure de route, dans une parcelle d'un peuplement originel en Colombie-Britannique intérieure. L'étude avait pour but de déterminer la productivité et le coût de chacune des phases de la récolte, et d'étudier les interactions entre les phases.

L'équipement utilisé comprenait principalement une abatteuse-groupeuse Caterpillar FB221, un débardeur à pince John Deere 740A, deux ébrancheuses-tronçonneuses Timberjack 90, et une chargeuse Caterpillar LL229 dotée d'un grappin à talons jumelés pour le chargement bidirectionnel des grumes. Le volume total de coupe était de 24 146 m^3, le volume moyen d'une pièce de bois de 0,29 m^3, et le coût direct de débardage entre la souche et le camion de \$8.11/m^3. La construction des routes représentait \$0.25/m^3, et le coût des bouteurs nécessaires pour tirer les camions sur les sections de routes boueuses, s'élevait à \$0.06/m^3. Ces coûts ont été calculés par FERIC et ne sont pas nécessairement les coûts réels encourus par la compagnie ou l'entrepreneur.

Les résultats de l'étude montrent qu'il fallait approximativement 1,5 heure d'abattage et de façonnage pour chaque heure de débardage, et environ 1,5 heure de débardage pour chaque heure de chargement. La production pour une phase variait de 544 m^3 par poste de travail de 8 heures pour la chargeuse, à 240 m^3 pour les ébrancheuses-tronçonneuses TJ90. L'abattage et le façonnage représentaient chacun 33% des coûts directs d'exploitation, alors que le débardage et le chargement correspondaient chacun à environ 17%.

Le taux d'utilisation des machines passait de 67% pour une ébrancheuse-tronçonneuse TJ90 à 92% pour la chargeuse LL229. Les principales causes de temps morts étaient les retards dus à une organisation déficiente, ainsi que les réparations et l'entretien. Dans le cas du débardeur et des ébrancheuses-tronçonneuses, jusqu'à 10% du temps total d'un poste de travail et 7% du temps productif étaient perdus à attendre du bois, parce que l'abatteuse-groupeuse était incapable d'abattre suffisamment d'arbres pour que les autres machines travaillent à pleine capacité. L'addition d'une seconde abatteuse-groupeuse mit un terme aux temps morts causés par l'insuffisance d'approvisionnement.

Les réparations nécessaires variaient d'une machine à l'autre. La chargeuse LL229 était celle qui demandait le moins de temps de réparation, soit 2,5 heures par 100 heures-machines productives (HMP), et celle qui en demandait le plus était l'une des ébrancheuses-tronçonneuses TJ90, soit 23,8 heures par 100 HMP. En général, les accessoires d'abattage et de façonnage demandaient de nombreuses réparations.

On constata peu de variation dans la productivité par HMP entre les postes de jour et de nuit. Toutefois, le taux d'utilisation était généralement plus élevé durant le poste de nuit, de sorte que la production par poste se trouvait plus forte. Cela s'explique principalement par le fait que les réparations mineures étaient prévues durant le jour, ce qui ajoutait de 0,3 à 0,6 heure au temps de réparation par poste.

INTRODUCTION

As part of its harvesting-systems evaluations project, FERIC undertook to monitor a roadside-logging system as a whole, rather than to isolate one machine for study. The objectives of this study were to determine equipment performance and costs, and to document how one machine's productivity affects another's performance.

Roadside logging has become an increasingly important system of logging in the Interior of British Columbia. Landings are not required for roadside logging, thus eliminating their cost, reducing site disturbance, and reducing the interference between logging phases caused by landing congestion. Instead of landings, stems are piled along the roadside (windrowed) for processing and loading. Safety is also improved because the workers are inside protective cabs at all times. However, capital costs are increased, and it becomes more important to ensure maximum machine utilization to ensure lowest costs.

The study was conducted in cooperation with Quest Wood Products Ltd. of Quesnel, B.C. The company harvests much of its timber supply from low-volume pine stands where the average tree size is small and the logging system must be designed to process a large number of stems rapidly to minimize logging costs. The logging contractor employed during the study had used roadside logging since 1986. His fleet consisted of one feller-buncher, one grapple skidder, two stroke delimbers, and one butt-and-top log loader, plus miscellaneous other equipment.

SITE AND SYSTEM DESCRIPTION

The study block was located approximately 85 km west of Quesnel, B.C. The species distribution information shown in Table 1 was obtained from the company's operational cruise data and the total volume was derived from the weigh-scale of all production. The data in Table 2 on log-size distribution were obtained from four sample truck loads which were scaled for stumpage purposes. The site was on a gently rolling ridgetop and the slope averaged 11%. The terrain was typical of Quest Wood Products' operating areas west of Quesnel. Figure A shows a typical stand of spruce and pine within the block and Figure B shows the study block.

Table 1. Site and Stand Description

Area	97.5 ha
Total volume	24 146 m^3
Volume/ha	248 m^3/ha
Species distribution	
Pine	58%
Spruce	30%
Balsam	12%
Aspect	Ridgetop: North to south aspect
Average slope	11%
Terrain	Even to gently rolling
Underbrush	Light

Table 3 lists the equipment used to harvest the study block. Trees were mechanically felled and bunched, then skidded to roadside with a grapple skidder where they were piled in windrows for processing and loading. Falling, skidding, and processing operated two shifts per day for five days per week, while loading and hauling operated one shift per day for five days per week. The operators alternated day and night shifts on a two-week cycle.

Table 2. Log-Size Distribution

Butt-diameter class (cm)	% distribution (by pieces)	Avg log volume (m^3)	Avg log length (m^3)
10	8	0.06	5.4
20	72	0.23	10.5
30	18	0.59	14.1
40	2	0.96	12.2
All	100	0.29	10.8

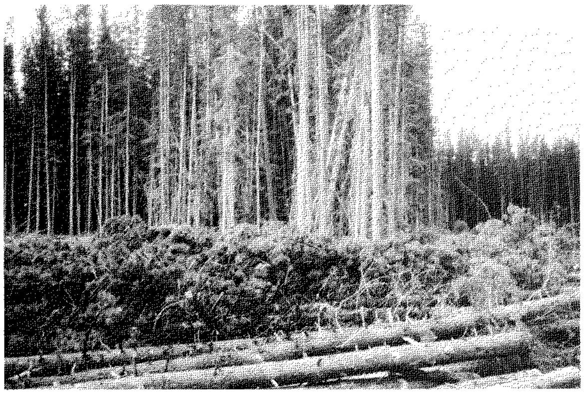

Figure A. Typical Spruce and Pine Stand in the Study.

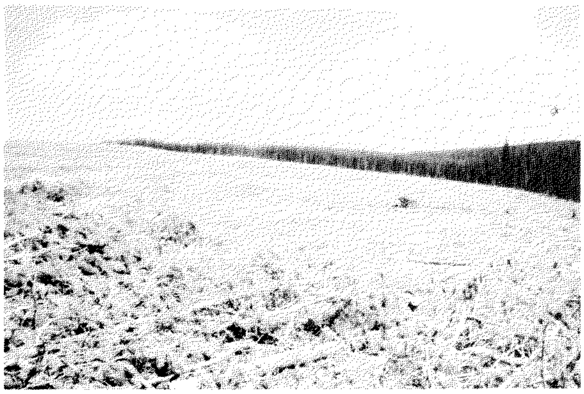

Figure B. Study Block After Harvesting.

Table 3. Logging Equipment

Model	Model year	No. of shifts/day	Current selling price
Falling			
Caterpillar FB221	1986	2	$391 000
John Deere 693B	n/a	1	$384 000
Caterpillar FB217	1987	-	$284 000
Skidding			
John Deere 740A	1985	2	$220 000
Processing			
Timberjack TJ90#1	1986	2	$360 000
Timberjack TJ90#2	1986	1 - 2	$360 000
Loading			
Caterpillar LL229	1985	1	$420 000
Trucking			
Various - 9 trucks	Various	1	$130 000 to $165 000
Other			
Caterpillar D8H bulldozer	n/a	n/a	$100 000
Clark Ranger 668 skidder	n/a	n/a	$ 40 000

The contractor usually preferred to maintain five to seven days' inventory between logging phases for flexibility and to avoid interference between equipment. However, start-up in the block was delayed for various reasons, and both the company and contractor were anxious to start each phase as quickly as possible when logging finally commenced. Therefore, skidding and processing both started four days after falling, and the loading five days after that.

Falling

Falling was carried out mainly with a Caterpillar FB221 feller-buncher using a Koehring 51-cm-diameter circular-saw felling head. One operator was new to the feller-buncher but had several years of experience on other equipment, while the second operator had one year of experience on the feller-buncher. The feller-buncher was approximately one year old.

Since the FB221 feller-buncher was unable to provide sufficient felled inventory, a John Deere 693B with a Denis twin circular-saw felling head was hired on a subcontract basis. The owner/operator had several years of experience operating feller-bunchers.

A third feller-buncher was used for a short time on the study block. Finning Ltd. supplied a Caterpillar FB217 feller-buncher for a demonstration, but FERIC did not monitor its performance.

The falling pattern was dictated by the preferred skidding direction which was directly up or down the slope. The feller-bunchers started by cutting a corridor along the back boundary or midway between the parallel roads, then working back and forth across the slope. Trees were grouped in bunches of six to ten stems, with the butts facing the truck road. Figure C shows the block layout, with typical falling and skidding patterns, and Figure D shows the FB221 feller-buncher during operation.

Road Building

Truck roads were built with a Caterpillar D8H bulldozer after falling and prior to skidding. The contractor operated the D8H bulldozer in addition to doing his normal supervision duties. The study block was 97.5 ha, and had 4.9 km of road for a road density of 50 m/ha. The maximum skidding distance was about 300 m, with the average distance to the boundary approximately 220 m. Company crews did the engineering layout for the truck roads.

Skidding

A two-year-old John Deere 740A grapple skidder was used for skidding. It operated for two shifts per day and both operators had several years of experience on the skidder.

The skidder generally pulled two bunches per turn. Trees were dropped at the roadside and their butts aligned to the road edge with the skidder blade. Depending on stand density and skidding distance, the piles were up to 3 m high, although most were about 2 m high. The skidder operators left low openings in the piles to maintain access to the block. Figure E shows the 740A skidder pulling an uphill turn.

Processing

Two Timberjack TJ90 processors were used during the study. One worked two shifts per day, while the other was operated either one or two shifts per day. The TJ90 processors consisted of a Denis Model KS telescoping-boom stroke delimber mounted on a Timberjack rubber-tired carrier (Figure F).

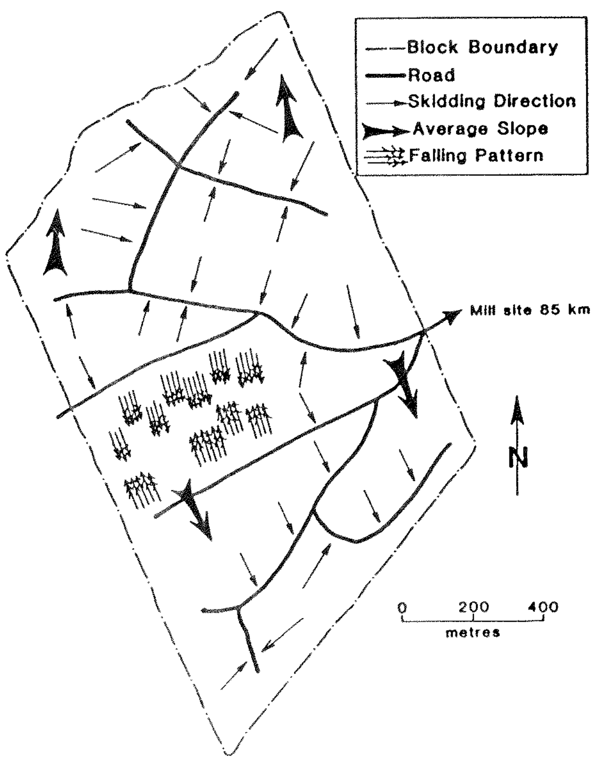

Figure C. Study-Block Layout.

Three of the four operators had from 6 to 8 months of experience on the processors, but the fourth operator had no machine experience and was considered a trainee operator.

The processor operators varied their work patterns depending on the inventory of skidded stems. Where the inventory was adequate, the two machines worked 100-200 m apart, one on each side of the road. At other times, the stems were processed as soon as they were skidded. A typical windrow of processed logs is shown in Figure G.

Loading, Hauling, & Other Activities

Loading was carried out with a Caterpillar LL229 butt-and-top log loader equipped with a Tanguay grapple and boom. The loader was about 18 months old. Two different operators were used during the study; the first was experienced on feller-bunchers but was new on the loader, and the second was fully experienced on the loader. The loader travelled to the far end of each spur road to begin loading, and required two passes to complete the loading from both sides of the road.

Nine highway trucks were used to haul the logs to the mill, and each averaged about two trips per day. The average haul distance was 85 km. The main configuration was a cab-over tractor with a jeep and

Figure D. FB221 Feller-Buncher.

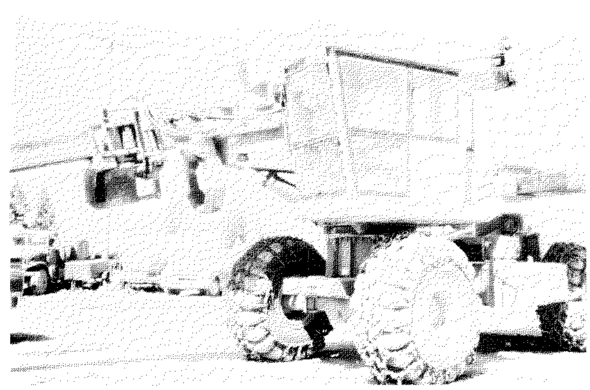

Figure F. Timberjack TJ90 Processor.

Figure E. 740A Skidder.

Figure G. Processed Logs Ready for Loading.

triaxle trailer. This truck configuration was a consideration in the loading pattern, i.e. commencing at the end of each spur, since the tractor-jeep/triaxle trailer configuration is very difficult to drive in reverse once the trailer is unloaded. This loading pattern had two disadvantages:

a) Cycle time was increased because the loader operator swung the logs over the back of the truck (Figure H). This was done to reduce the risk of truck damage that might result from swinging logs over the cab.

b) The loader could not work on the same spur as the processors because access for the trucks would be blocked.

The final piece of equipment used in this logging system was a Clark Ranger 668 line skidder which was used to pull trucks through muddy sections of road. It was operated by the contractor or another operator as the need arose.

Planned post-harvesting treatment involved piling and burning debris left at the roadside, and possibly scarifying the setting. The company planned to rely on natural regeneration and to check stocking levels in two to four years.

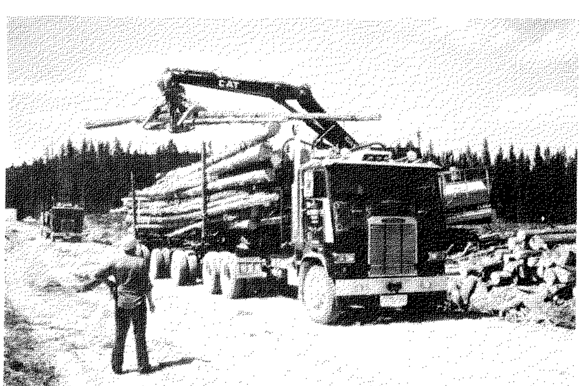

Figure H. Caterpillar LL229 Loader with Butt-and-Top Grapple Loading a Tractor-Jeep/Triaxle Trailer Log Truck.

STUDY METHODS

Each machine was equipped with a Model DSR Servis Recorder to monitor working and delay times. The operators identified each delay over 10-min duration and provided an explanation of its cause. Delays under 10-min duration were considered part of productive time. FERIC grouped the delays according to their causes, and measured productive and non-productive times from the Servis Recorder charts using a digitizing tablet connected to an IBM-compatible computer.

The total harvested volume was derived from the actual weigh-scale of all production delivered to the mill. When more than one machine or machine shift was used for a phase, production was allocated between machines or shifts based on the operators' daily piece counts.

The 693B and the FB217 feller-bunchers were not equipped with Servis Recorders. The 693B feller-buncher operator reported total trees cut and total cutting hours, and these were used to estimate production. The total cutting time for the FB217 feller-buncher was reported, and its cutting volume was estimated based on the average number of trees per hour for the FB221 feller-buncher. Other than calculating their portion of total production, these machines are not used in the data analysis.

The study was carried out over seven weeks, starting in late May 1987.

RESULTS AND DISCUSSION

Scheduling Intensity

Every shift for each machine was recorded from the first day to the last day worked on the study block. Shifts were classified as production shifts, non-production shifts, or scheduled shifts off. Any amount of production classified a shift as a production shift. A non-production shift was one which was scheduled for production but where some event such as repairs, vacations, or a lack of raw materials prevented the machine from working. Scheduled shifts off were weekends and statutory holidays.

Table 4 shows the scheduling intensity for the five main machines. Most machines averaged 26-30% scheduled shifts off, but the FB221 feller-buncher had only 20% scheduled shifts off because it was operated for several weekend shifts to increase the inventory of felled trees. It also had 79% production shifts compared to 61-70% for the other machines.

Non-production shifts were divided into mechanical and non-mechanical classes. Non-mechanical lost shifts were due to the lack of stems to skid or process. The 740A skidder lost 7% of its shifts, the

Table 4. Scheduling Intensity

	FB221-Feller-buncher		740A Skidder		TJ90#1 Processor		TJ90#2 Processor		LL229 Loader	
	Shift	%	Shift	%	Shift	%	Shift	%	Shift	%
Scheduled shifts off	16	20	23	28	23	28	16	26	13	30
Production shifts	65	79	54	65	55	67	38	61	30	70
Non-production shifts										
Mechanical	1	1	0	0	0	0	2	3	0	0
Non-mechanical	0	0	6	7	4	5	6	10	0	0
Total	82	100	83	100	82	100	62	100	43	100

TJ90#1 processor 5%, and the TJ90#2 processor 10% of its potential shifts for this reason. These shifts were lost during the first half of the study. However, during the latter half of the study, the second feller-buncher was hired and no further shifts were lost because of insufficient felled inventory.

The TJ90#2 processor was on-site about 20 shifts less than the other machines because:

a) Its start-up was delayed until there was sufficient skidded inventory for a second processor.

b) It was initially scheduled for one shift per day to increase the inventory of skidded stems.

c) Muddy conditions at the end of the study slowed skidder productivity. There was insufficient skidded inventory to operate two processors, and the TJ90#2 was shut down.

The LL229 loader was scheduled for one shift per day, and it worked for every scheduled shift during the study period.

Shifts with Production

The scheduled time for shifts with production was divided into three categories: productive machine time, non-mechanical delay time, and mechanical delay time (Table 5). The average utilization for the five machines during the study was approximately 78%. The LL229 loader had the highest utilization at 92%, and the TJ90#2 processor the lowest at 67%.

Delay Times - The delay times were examined to explain the range in utilization. A major reason for the TJ90#2's low utilization was high repair time, and this is discussed in a later section.

The non-mechanical delay times were further divided into two categories: organizational delays, which are generally controllable by company policy, and operational delays, which are not controllable by policy. Table 6 shows that, because the FB221 feller-buncher was unable to fall enough trees to maintain sufficient inventory, waiting for wood was the main organizational delay affecting the skidder and processors. The remaining organizational delays were for such things as the LL229 loader waiting for trucks, move-in time for the TJ90#1 processor, and operators working on other duties. Other duties included operating the spare skidder to pull trucks through muddy sections of road, and using the TJ90#1 processor to lift repair parts onto the FB221 feller-buncher. The main operational delay was for breaks. Meal times were excluded from machine times and are not shown in any summaries.

Production Allocation - The scaled volume for the study block was 24 146 m^3. Table 7 shows the calculated volume distribution between shifts based on the operators' daily tree counts for the falling and processing phases.

Turn counts for the skidder were incomplete, and the day and night shifts were combined for analysis. There were no tree counts for the FB217 feller-buncher. Its tree count was estimated from its total operating hours and the average cutting rate and utilization for the FB221 feller-buncher.

The volumes for the trainee processor operator have been excluded from Table 7 and all subsequent production calculations. His average productivity was approximately 14.7 m^3/PMH and was not representative of the TJ90 processor's potential productivity.

Summary of Productivity - The production rates for the four main machines are shown in Table 8. The loading phase will be considered separately from the falling, skidding, and processing phases.

The utilization for the 740A skidder was 80% during the study. However, if its wait-for-wood delays are eliminated, its scheduled machine hours (SMH) would be 534.6 and the utilization would be 84%. Similarly, the average utilization for the processors would be 76% if their wait-for-wood delays are removed.

The skidder had the highest productivity (m^3/PMH) and the highest utilization as well. Using the calculated utilization when wait-for-wood delays are eliminated, its productivity was 361 m^3/8-h shift. There

Table 5. Time Distribution for Productive Shifts

	FB221 Feller-buncher		740A Skidder		TJ90#1 Processor		TJ90#2 Processor		LL229 Loader	
	Hours	%	Hours	%	Hours	%	Hours	%	Hours	%
Productive machine hours (PMH)	547.0	78	449.5	80	434.6	75	264.6	67	329.1	92
Non-mechanical delay hours (NDH)										
Organizational	0.8	0	30.1	5	30.9	5	26.8	7	10.6	3
Operational	24.7	4	19.8	4	12.4	2	5.5	1	1.0	0
Mechanical delay hours (MDH)										
Wait mechanical	3.7	0	0.0	0	7.6	1	13.8	4	0.0	0
Repair	80.8	11	26.4	5	53.2	10	54.9	14	8.2	2
Service	45.9	7	36.0	6	38.1	7	27.6	7	8.9	3
Scheduled machine hours (SMH)	702.9	100	561.8	100	576.8	100	393.2	100	357.8	100
Average shift length (h)	10.8		10.4		10.5		10.4		11.9	
PMH/shift (h)	8.4		8.3		7.9		7.0		11.0	
Utilization[a] (%)	78		80		75		67		92	

[a] Utilization = PMH/SMH

Table 6. Non-Mechanical Delay Times

	Hours				
	FB221 Feller-buncher	740A Skidder	TJ90#1 Processor	TJ90#2 Processor	LL229 Loader
Organizational delay					
Wait-for-wood	0.0	27.2	19.4	25.2	0.0
Wait other machine	0.0	0.0	0.9	1.5	10.6
Other work for operator	0.0	2.5	5.8	0.1	0.0
Move to new area	0.0	0.0	4.8	0.0	0.0
Miscellaneous	0.8	0.4	0.0	0.0	0.0
Total	0.8	30.1	30.9	26.8	10.6
Operational					
Break	13.6	17.0	8.8	5.4	0.3
Plan work sequence	3.4	0.0	0.4	0.0	0.0
Miscellaneous	7.7	2.8	3.2	0.1	0.7
Total	24.7	19.8	12.4	5.5	1.0

Table 7. Production Allocation

	Falling				Processing			
	FB221 Feller-buncher		JD693B Feller-buncher	FB217 Feller-buncher[a]	TJ90#1 Processor		TJ90#2 Processor[b]	
	Day	Night	Day	Day	Day	Night	Day	Night
Stem count	42 429	40 070	10 583	4 450	28 547	27 858	11 584	3 092
Production (%)	43.5	41.1	10.9	4.5	36.7	35.9	14.9	4.0
Volume (m^3)	10 503	9 924	2 632	1 087	8 866	8 652	3 598	966

[a] Estimated.
[b] Trainee operator excluded.

Table 8. Productive Summary

	Falling			Skidding	Processing						
	FB221 Feller-buncher			740A Skidder	TJ90#1 Processor			TJ90#2 Processor			Both Processors[a]
	Day	Night	Combined	Combined	Day	Night	Combined	Day	Night	Combined	Combined
Production (m^3)	10 503	9 924	20 427	24 146	8 866	8 652	17 518	3 598	966	4 564	22 082
Production (trees)	42 429	40 070	82 499	n/a	28 547	27 858	56 405	11 584	3 092	14 676	71 081
Shifts worked	35	30	65	54	30	25	55	14	5	19	74
PMH	279.7	267.3	547.0	449.5	221.3	213.3	434.6	98.7	25.4	124.1	558.7
m^3/PMH	37.6	37.1	37.3	53.7	40.1	40.6	40.3	36.5	38.0	36.8	39.5
Trees/PMH	152	150	151	n/a	129	131	130	117	122	118	127
SMH	374.6	328.3	702.9	561.8	315.4	261.4	576.8	144.8	53.4	198.2	775.0
Utilization (%)	75	81	78	80	70	82	75	68	48	63	72
Production/ 8-h shift (m^3)	226	240	233	344	225	266	242	199	146	185	228
Utilization - Wait-for-wood delays removed	75	81	78	84	74	83	78	70	63	68	76
Production/ 8-h shift (m^3)	226	240	233	361	237	270	251	204	192	200	240

[a] Trainee operator excluded.

were no wait-for-wood delays for the FB221 feller-buncher, and its productivity was 233 m^3/8-h shift. The average productivity of the two processors was 240 m^3/8-h shift each when the wait-for-wood delays are eliminated. Using these production rates, 1.5 feller-buncher and 1.5 processor hours are required for each skidder hour. Depending on equipment availability, mill requirements, fixed costs, and setting layout, the logging manager and contractor can use this number to plan the equipment fleet, production quota, and hours of work.

Ideally, the production rates for all phases should be matched exactly, so that no phase is delayed by another. However this is very difficult to achieve under actual conditions where the balance between phases changes as operating conditions change. Inventories between phases can buffer production-rate differences, but eventually one phase will set the pace for the system.

In the system studied, the FB221 feller-buncher was the critical machine until a second feller-buncher was added. Two processors were used, but not on a full-time basis. Only one skidder was used, and it had some excess capacity, as shown by its wait-for-wood delays. It would have been the critical machine in the system if these delays had been eliminated, however, a second feller-buncher would have been required part-time. If a second feller-buncher had been fully utilized, an additional skidder would have been required part-time. Similarly, to fully utilize two processors, a second full-time feller-buncher and part-time skidder would be required.

As an example of the options available in choosing the amount of equipment to use, the system could be planned to have two skidder shifts, three feller-buncher, and three processor shifts per day. Alternatively, the feller-buncher and processor could each work two shifts per day and the skidder would be idled part-time. Another option would be to alter road spacing to match more closely the skidder's productivity to the other machines. If the average skidding distance was reduced, road costs would increase, but the skidder could service two full-time feller-bunchers and processors. Conversely, if the average skidding distance was increased, road costs would decrease, and the skidder might service only one feller-buncher and processor. Clearly, there is flexibility in allocating equipment to meet various corporate and contractor objectives.

Comparisons of Day-Shift Productivity and Night-Shift Productivity - The productivity in cubic metres per PMH showed little variation between day and night shift. The FB221 feller-buncher's productivity was approximately 1% higher during the day and the TJ90#1 and TJ90#2 processors had higher productivity at night by 1% and 4% respectively.

However, utilization varied between shifts with night shift generally having higher utilization than day shift. Repair hours were 0.3-0.6 hours per shift longer on day shift than night shift because, presumably, minor malfunctions were left unrepaired on night shift when no mechanic was available. The difference in utilization made the night shifts more productive on an 8-h basis. The exception was the

TJ90#2 processor. It lost 8.6 h one night and was down until the following morning with a breakdown in its hydraulic system. If this breakdown had not occurred, its utilization would have been 64% compared to its actual 48%, and closer to its day-shift utilization of 68%. The TJ90#2 processor also had several long wait-for-wood delays, and since only five night shifts were recorded, these delays disproportionately affected its utilization.

Loader Productivity - The loading productivity is summarized in Table 9. The loader averaged 16.9 loads with 47.7 m^3/load over an average shift of 11.9 hours. The average loading time was 0.65 PMH per load and included the time required to unload the truck trailers. The remaining time was evenly divided between repairs, service, and waiting for trucks.

Detailed Timing of the TJ90 Processor - As mentioned, the TJ90 processor (Figures I and J) is a Denis Model KS stroke delimber mounted on a Timberjack rubber-tired carrier. FERIC made some detailed-timing observations of the TJ90#1 processor to examine its work cycle.

The Denis stroke delimber consists of a telescoping boom, with two sets of grab-arms and two hydraulically driven chain saws. During processing, the stem is held stationary with the rear grab-arms and, if necessary, is cut with the rear chain saw ("long-butted"). Stems larger than the maximum stroke length can be processed by using a reciprocating motion, or "second stroke."

Figure I. Processed Logs and TJ90#1 Processor.

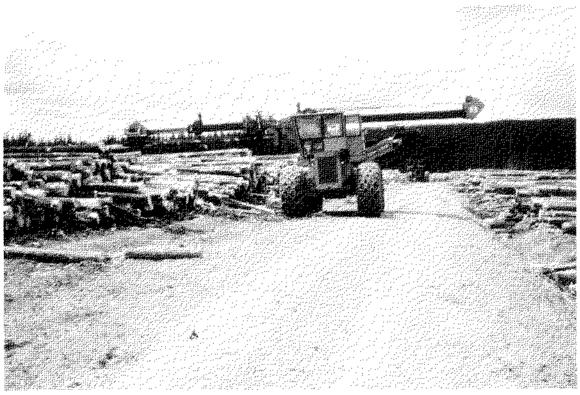

Figure J. TJ90#1 Processor.

A summary for the total detailed-timing period for the TJ90#1 processor is shown in Table 10. The processor was observed handling up to three trees at a time, but it usually processed stems individually with an average of 1.07 stems per cycle. Six percent of the stems were forked and produced three logs per stem. Otherwise, each stem produced one log because the average stem size was small.

The productive time (Table 11) was divided into three components: net processing time, move time, and minor delay time. Net processing was further divided into three elements: grasp log time (which ended when the stem was secured in the rear grab arms), delimb and cut time (which ended when the final topping cut was made), and discharge time

Table 9. Loading Summary

Volume (m^3)	24 146
Truck loads	506
Load average (m^3)	47.7
Loader productive hours	329.1
PMH/load	0.65
Loader shifts	30
Loads/shift	16.9
Average shift length (h)	11.9
Loads/8-h shift	11.4
Production/8-h shift (m^3)	544

Table 10. TJ90#1 Processor Detailed Timing - Total Time

Total time	187.0 min
Productive time	148.5 min
Processor cycles	362
Stems processed	386
Logs manufactured	442
Forked stems	6%

Table 11. TJ90#1 Processor Detailed Timing - Productive Time

Time Distribution	Min/cycle		%	
Net processing				
Grasp log	0.15		36	
Delimb and cut	0.15		36	
Discharge	0.09		23	
Subtotal		0.39		95
Moving		<0.01		1
Minor delay		0.02		4
Productive time		0.41		100

(which ended when the log was dropped from the processor).

Move and minor delay times made up a small portion of the productive time. The minor delays were primarily for decking logs and moving debris.

Nearly one quarter of the processor's productive time was spend discharging the log. It may be possible to reduce discharge time by altering the operating technique. Normally, each stem was held with the rear grab-arms about 1 to 2 m from the butt, and had to be pulled out of the rear grab-arms after the final cut was made. If the stem were held closer to the butt, it could simply be dropped, eliminating the time required to pull the log out of the grab-arms. However, this would affect the alignment of the outfeed deck, and therefore might affect the loader's productivity.

Butt diameters were estimated to the nearest 10 cm as the stems were processed, and processing times calculated for each class (Table 12). In addition, whether or not the stem was long-butted or required a second stroke was recorded. The size-class distribution refers to the detailed-timing period and is not representative of the whole stand. The class volumes were calculated from four truck loads which were sample-scaled by the company and then adjusted to account for multiple logs per stem.

The processing time per stem and the volume processed per minute increased as butt diameter increased. This resulted in lower daily tree counts but higher daily volumes as stem size increased. Because the shift-level productivity was calculated using average tree volumes, the effect of stem size on productivity was lost in the shift-level analysis.

Four percent of the observed logs were long-butted, with an average increase in processing time of 0.07 min/stem. The 10-cm diameter class had the highest increase in processing time -- 0.13 minutes.

A second stroke was required for 38% of the stems, and an extra 0.10 min/stem was required each time a second stroke was used. However, the processing times for the 30-cm-diameter-class stems actually decreased when a second stroke was used, the opposite of what might be expected. Possibly the boom slows down at full extension and increases the processing time when only one stroke is used. If so, it may be advantageous to make two short, quick strokes on the 30-cm diameter-class stems rather than one long stroke.

Repair and Service

Repair and service time occupied from 5% to 21% of time during productive shifts, plus 0% to 3% of total shifts. This section highlights some of the repairs. Table 13 presents a summary of repairs and service for the FB221 feller-buncher, the skidder, the processors, and the loader.

Summaries of all the machines' activities, including the duration and frequency of all repair delays are shown in Appendix I.

There was a wide range in Mechanical Downtime Ratio (MDR) for repairs on the various types of equipment, ranging from 2.5 for the LL229 loader to 23.8 for the TJ90#2 processor. However, the MDR for service showed less variation, averaging from 8 to 10, except for the LL229 loader which averaged 2.7. Time spent waiting for parts or mechanics is not included in the MDR.

FB221 Feller-Buncher - The boom and felling head accounted for 60% of repairs to the FB221 feller-buncher. The boom knuckle pin broke twice, and 15.6 hours were required to replace it. Hydraulic component repairs accounted for 15.5 hours of the repair time, and approximately 55% of this time was for structural damage to the tool and grab-arm cylinders (broken mountings). The remainder was for replacing hoses and fittings. The wiring for the grab-arms was replaced, accounting for part of one lost shift, as well as 8.1 hours of on-shift repairs. Sharpening the saw blade accounted for 4.3 hours of repair time.

The FB221 feller-buncher has a self-levelling cab, and the cab-tilt cylinders broke twice. Part of the lost shift was spent repairing the cab-tilt cylinder. Other frequent carrier repairs were to recharge the air conditioner and to repair lights.

Unspecified repair accounted for 14% of the mechanical delays. These all occurred during one week when the operators neglected to provide explanatory notes with the Servis Recorder charts.

The FB221 feller-buncher was serviced every shift, using a total of 8.4 hours per 100 PMH.

740A Skidder - There were two recurring mechanical problems on the 740A skidder.

a) Alternator. The alternator was replaced five times over eight working days. Once the short circuit which caused the problem was identified and repaired, there were no further electrical problems on the 740A skidder. Repairs totalled 8.6 hours.

b) Grapple brake. A hydraulically operated grapple brake, activated by the grapple-closing cylinder, was installed on the 740A skidder. The brake was engaged when the grapple was fully opened, and was released when the grapple was closed. This was the prototype of the brake and the concept worked well, keeping the grapple stationary while the brake was engaged. However, six repairs totalling 8.3 hours were required on the

Table 12. Summary of Processing Time by Butt-Diameter Class

Butt diameter class (cm)	Overall				Long-butting				Second stroke			
					Without		With		Without		With	
	%	m^3/ stem	Min/ stem	m^3/ min	%	Min/ stem	%	Min/ stem	%	Min/ stem	%	Min/ stem
10	38	0.06	0.30	0.20	97	0.30	3	0.43	92	0.30	8	0.39
20	46	0.23	0.40	0.58	97	0.40	3	0.40	46	0.36	54	0.43
30	14	0.61	0.52	1.17	93	0.52	7	0.59	27	0.61	73	0.49
40	2	0.97	0.78	1.24	100	0.78	0	-	33	0.80	67	0.78
All	100	0.23	0.39	0.58	96	0.39	4	0.46	62	0.35	38	0.45

Table 13. Repair and Service Summary[a]

	FB221 Feller-buncher		740A Skidder		TJ90#1 Processor		TJ90#2 Processor		LL229 Loader	
	Hours	MDR[b]	Hours	MDR[b]	Hours	MDR[b]	Hours	MDR[b]	Hours	MDR[b]
Repair										
Carrier	19.5	3.5	13.6	3.0	8.0	1.8	29.2	11.0	0.6	0.2
Motor/drive train	3.1	0.6	0.2	0.1	9.5	2.2	0.9	0.4	3.6	1.1
Attachment[c]	54.3	9.9	12.4	2.8	35.7	8.2	32.8	12.4	4.0	1.2
Unspecified	11.9	2.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	88.8	16.2	26.4	5.9	53.2	12.2	62.9	23.8	8.2	2.5
Service										
Carrier	0.5	0.1	2.2	0.5	1.6	0.4	0.6	0.2	0.0	0.0
Motor/drive train	4.5	0.8	1.0	0.2	2.3	0.5	0.9	0.3	0.5	0.2
Attachment[c]	0.0	0.0	0.0	0.0	1.2	0.3	0.0	0.0	0.0	0.0
General	40.9	7.5	32.8	7.3	33.0	7.6	26.1	9.9	8.4	2.5
Subtotal	45.9	8.4	36.0	8.0	38.1	8.8	27.6	10.4	8.9	2.7
Total	134.7	24.6	62.4	13.9	91.3	21.0	90.5	34.2	17.1	5.2
PMH	547.0		449.5		434.6		264.6		329.1	

[a] Includes both production and non-production shifts.

[b] MDR - Mechanical Downtime Ratio equals repair and service hours per 100 productive machine hours.

[c] Attachments:
FB221 Feller-buncher - Boom and felling head
740A Skidder - Log grapple
TJ90 Processor - Delimber
LL229 Loader - Boom and grapple

brake, indicating the design was inadequate to withstand operating stresses.

Other repairs on the 740A were minor in nature.

TJ90 Processors - The two processors had dissimilar repair experience: the TJ90#1 processor had an MDR of 12.2, and the TJ90#2 processor had nearly twice that amount at 23.8. However, the TJ90#2 processor had only 60% of the productive hours as the TJ90#1 processor, thus each repair had a proportionately larger effect on the MDR.

Most of the MDR difference was due to repairs on the carrier, which varied for each processor. The TJ90#1 processor had four repair delays, totalling 6.8 hours, when its transmission was sticking in gear. Other lengthy repair delays on the TJ90#1 processor involved sealing the main hydraulic tank, repairing the rear-axle stabilizer arm, and refilling the radiator three separate times. The TJ90#2 processor had an intermittent problem in its electrical system. There were 13 delays, totalling 16 hours, plus one shift with no production, to find and correct the short circuit. The alternator, batteries, and solenoid were each replaced twice before the fault was corrected.

Repairs on the delimber itself accounted for two-thirds of repairs on the TJ90#1 processor and one-half on the TJ90#2 processor. The repairs for various components of the delimbers were examined, and the MDRs for structural repairs (approximately 2.0), cutting tools (approximately 3.5), and miscellaneous parts (approximately 1.0) were found to be similar for the two machines. However, the rates of repairs for hydraulics and electronics for the TJ90#2 processor were twice that of the TJ90#1 processor (3.9 versus 1.9 for hydraulics, and 1.7 versus 0.8 for electronics). The hydraulic control block for the topping saw and grab-arms on the TJ90#2 processor was repaired twice, accounting for most of the difference in the hydraulic MDRs. Both machines had MDRs of approximately 2 for broken hydraulic lines and fittings. Replacing wiring and switches were the main electrical repair delays on both delimbers. The repairs were not specific to any single component.

Both processors experienced numerous delays for repairing or replacing saw chains and bars. On average, the processors encountered a chain- or bar-repair delay once every 1.5 shifts, and the average duration was 0.3 hours. Approximately 42% of the delays involved tightening the chain and 23% involved replacing broken chains. Thirty percent of the delays were caused by broken or bent bars and 5% by broken bar tips.

In addition to repairs, the processors averaged approximately 0.2 hours per shift for servicing (fuelling, greasing, oil levels).

LL229 Loader - The LL229 loader was found to be mechanically reliable during the study, with an MDR for repairs of only 2.5. Approximately one-half of the delays for the attachment occurred on the first shift after spring start-up. Some fittings in the grapple swivel had been left loose and required tightening. The remaining attachment repairs were for three broken hoses. The other long delay occurred when a mechanic from the equipment dealership was required to adjust the motor. Downtime was 3.6 hours.

Service time for the LL229 loader was less than the other machines since the loader was usually serviced between trucks, during productive time. These service delays were less than 10 minutes in duration and they did not appear as separate activities on the Servis charts. Fuelling was done at the end of the shift and accounts for the service delays.

Cost Calculations

FERIC calculated hourly cost rates for each machine (Appendix II). These are not the actual costs incurred by the company or contractor, and do not include such costs as crew and machine transportation, supervision, office overhead, and profit and risk. Interest charges are shown in Appendix II, but are excluded from the cost of production. The labour rates are IWA rates, and include 35% burden for fringe benefits. Costs are shown on an 8-hour shift basis and include the net hourly cost of one hour labour at overtime wage rates.

The production rates calculated in Tables 8 and 9 were used to calculate the cost/m³ for falling, skidding, processing, and loading. The costs are based on the productivity levels when the wait-for-wood delays were removed from the skidding and processing phases. Table 14 summarizes the daily productivities for each phase, as well as the percentage of direct logging cost, which totalled $8.11/m³.

The falling and processing phases were roughly equal in productivity and costs, with each costing approximately $2.70/m³, or 33% of direct logging cost. Skidding and loading each accounted for about 17% of the direct logging cost.

The productivity ratio in Table 14 expresses each machine's productivity relative to the loader's productivity. The skidder worked approximately 1.5 hours, and the feller-buncher and processors approximately 2.3 hours for each hour the loader worked. Expressed in other terms, the feller-buncher and processors included 1.5 shifts for each skidding shift.

The D8H bulldozer was used for approximately 75 hours to build truck roads. At $78.88/h, this amounted to $0.25/m³ for on-block road construction. An additional 17.5 hours were spent pulling trucks through soft sections of road, or $0.06/m³. Hours for the 668 skidder were not recorded.

Table 14. Phase Costs per Cubic Metre

	Falling	Skidding	Processing	Loading
m³/Day	233	361	240	544
$/Day	$639	$515	$641	$689
$/m³	$2.74	$1.43	$2.67	$1.24
Percent of cost	34	17	33	16
Productivity ratio	2.33	1.51	2.27	1.00
Total cost ($/m³)		8.11		

CONCLUSIONS

The machines in a logging system must be chosen to compliment the capacity and productivity of one another because system productivity is normally determined by the capacity of one phase. Delays will occur somewhere in the system if the total capacity of one phase is much different from any others for reasons such as individual machine productivity, the number of machines used in the phase, or their hours worked. Initially, in the system studied, falling was the critical phase and delays occurred for both skidding and processing. A second feller-buncher was added, falling capacity was increased, and skidding became the critical phase.

The organizational delays were primarily wait-for-wood delays. The skidder and processors lost from 5% to 10% of their potential shifts and up to 7% of their time during productive shifts because of insufficient inventory. When all delays were considered, utilization ranged from 67% for one TJ90 processor to and 92% for the LL229 loader.

Study results showed that production was 233 m^3/8-h shift for the feller-buncher, 361 m^3/8-h shift for the skidder, and 240 m^3/8-h shift for the processors. In other words, approximately 1.5 falling and processing hours were required for each skidding hour. Wait-for-wood delays were removed to derive these figures. These results were also seen in the final equipment fleet used by the contractor: one feller-buncher, one skidder, and one processor on two shifts per day each, and a second feller-buncher and processor on one shift per day. One log loader was used, and it averaged 544 m^3/8-h shift. It is possible that productivity per PMH would have been higher for the skidder and processors if there were no wait-for-wood delays because of an increase in operator motivation.

The total volume logged was 24 146 m^3 and the direct stump-to-truck logging cost was \$8.11/m^3. Road construction added \$0.25/m^3 and extra bulldozer costs were \$0.06/m^3. Falling and processing each accounted for 33% of costs, while skidding and loading each accounted for about 17%. Costs were derived by FERIC and are not the actual costs incurred by the company or contractor. Costs such as interest, overhead, machine and crew transport, and profit are not included.

Repair and service time accounted for 5% to 21% of scheduled machine time plus 0% to 3% of potential shifts. The LL229 loader required the fewest repairs, at 2.5 h/100 PMH, and the TJ90#2 processor the most at 23.8 h/100 PMH. Service time added from 2.7 to 10.4 h/100 PMH. In general, the falling and processing attachments required the most repairs, accounting for 48% to 67% of repairs. Frequent repairs on the feller-buncher were to repair hydraulic components such as fittings and mountings. Hydraulics were also problem areas in the processors, although repairs to the chain saws were also quite frequent.

There was little variation in productivity/PMH between day and night shifts. The TJ90#2 had the most variation, with 4% more productivity at night. Also, utilization was generally higher on night shift, so production per shift was higher. This was mainly because minor repairs were scheduled during the day where repair times were 0.3-0.6 h/shift longer.

Some detailed-timing data were collected on one TJ90 processor to examine its work cycle. Nearly one quarter of its processing time was spent discharging the logs and it may be possible to reduce this time by altering the operating technique. Also, for stems in the 30-cm diameter class, processing time was less when two strokes per stem were used rather than one stroke. This knowledge may help operators reduce processing times for stems of this size.

APPENDIX I

Summary of Activities During Production Shifts

	FB221 Feller-buncher		740A Skidder		TJ90#1 Processor		TJ90#2 Processor		LL229 Loader	
Activity	No. occ.	Hours	No. occ.	Hours	No. occ.	Hours	No. occ.	Hours	No. occ.	Hours
PRODUCTIVE TIME										
Prime function	253	547.0	198	449.5	264	434.6	163	264.6	78	329.1
OPERATIONAL DELAYS										
Coffee break	58	13.6	48	17.0	44	8.8	26	5.4	2	0.3
Rest break	2	0.7	-	-	-	-	-	-	-	-
Visitors to job site	2	0.5	-	-	1	0.1	-	-	-	-
Machine stuck or rolled over	1	0.6	-	-	1	0.2	-	-	-	-
Recce/plan work sequence	11	3.4	-	-	2	0.4	-	-	-	-
Discussion with supervisor	2	0.5	-	-	2	0.9	-	-	-	-
Repair/service aux.	-	-	4	2.2	4	1.7	-	-	-	-
Unexplained operational delay	9	2.6	2	0.5	1	0.3	1	0.1	1	0.6
Misc. operational delay	2	2.9	1	0.2	-	-	-	-	-	-
Total operational delays		24.8		19.9		12.4		5.5		0.9
ORGANIZATIONAL DELAYS										
Delay caused by fallers	-	-	10	27.2	-	-	-	-	-	-
Delay caused by skidder/yarder	-	-	-	-	8	19.4	8	25.2	-	-
Delay caused by loader	-	-	-	-	1	0.3	-	-	-	-
Delay caused by log haul	-	-	-	-	-	-	-	-	37	10.6
Delay caused by road builder	-	-	-	-	1	0.6	1	1.5	-	-
Move to new work area	-	-	-	-	1	4.8	-	-	-	-
Assisting other equipment	-	-	3	0.4	1	1.8	-	-	-	-
Operator on other activity	-	-	5	2.5	7	3.8	-	-	-	-
On-job training	1	0.1	-	-	-	-	-	-	-	-
New operator training period	-	-	-	-	1	0.2	1	0.1	-	-
Shift change	2	0.7	-	-	-	-	-	-	-	-
Total organizational delays		0.8		30.1		30.9		26.8		10.6
MECHANICAL DELAYS										
Wait parts	1	3.7	-	-	1	3.2	2	3.7	-	-
Wait repair personnel	-	-	-	-	1	4.3	2	10.1	-	-
Hydraulic lines - carrier	2	3.7	3	3.1	-	-	1	0.2	2	0.6
Hydraulic cylinders - carrier	2	3.7	-	-	-	-	-	-	-	-
Hydraulic controls - carrier	-	-	-	-	-	-	1	1.8	-	-
Hydraulic tank - carrier	2	1.9	-	-	5	3.9	-	-	-	-
Alternator/generator	-	-	7	8.0	-	-	6	9.1	-	-
Battery	-	-	1	0.6	-	-	4	2.4	-	-
Electric controls - carrier	-	-	-	-	-	-	1	1.5	-	-
Lights - carrier	7	3.6	-	-	1	0.2	-	-	-	-
Unspecified - carrier electric	1	0.5	-	-	-	-	-	-	-	-
Solenoid - carrier	-	-	-	-	-	-	2	3.0	-	-
Minor welding - carrier	-	-	-	-	1	0.5	-	-	-	-
Environmental system	6	2.8	-	-	-	-	-	-	-	-
Radio repair	-	-	-	-	1	0.2	-	-	-	-
Brake controls - carrier	-	-	-	-	-	-	2	3.2	-	-
Brake actuators - carrier	-	-	4	1.0	-	-	-	-	-	-
Suspension	1	0.8	-	-	1	3.3	-	-	-	-
Wheels/tires	-	-	1	0.9	-	-	-	-	-	-
Tracks	2	0.6	-	-	-	-	-	-	-	-
Unspecified motor repair	-	-	1	0.2	-	-	-	-	1	3.6
Motor controls	1	0.2	-	-	-	-	-	-	-	-
Transmission - carrier	-	-	-	-	4	6.8	-	-	-	-
Radiator	-	-	-	-	1	1.0	-	-	-	-
Fan/belt	1	2.9	-	-	-	-	-	-	-	-
Engine coolant	-	-	-	-	5	1.8	-	-	-	-
Oil cooler	-	-	-	-	-	-	1	1.0	-	-
Hydraulic lines - prime attachment	7	6.9	4	3.5	12	6.3	5	3.3	4	3.4
Cylinders - prime attachment	4	8.6	-	-	2	1.9	2	2.5	-	-
Hydraulic controls - prime attachment	-	-	1	0.2	-	-	2	3.2	1	0.6
Unspecified hydraulic - prime attachment	-	-	-	-	-	-	1	1.2	-	-
Wiring - prime attachment	1	8.1	-	-	1	0.4	2	2.0	-	-
Electric controls - prime attachment	1	0.3	-	-	3	1.7	3	2.5	-	-
Lights - prime attachment	-	-	-	-	2	0.9	-	-	-	-
Minor welding - prime attachment	-	-	-	-	1	0.6	1	1.4	-	-
Major welding - prime attachment	-	-	-	-	2	1.9	1	1.7	-	-
Guarding - prime attachment	-	-	-	-	-	-	1	0.8	-	-
Misc. structural - prime attachment	4	15.6	-	-	2	5.1	2	0.7	-	-
Cable/choker	-	-	-	-	2	5.0	-	-	-	-
Chain implement	-	-	-	-	23	6.1	18	5.1	-	-
Bar implement	-	-	-	-	7	2.9	8	4.5	-	-
Brakes - prime attachment	-	-	6	8.3	-	-	-	-	-	-
Spring - prime attachment	5	4.5	-	-	-	-	-	-	-	-
Drive chain - prime attachment	-	-	-	-	4	2.9	4	3.0	-	-
P.A.W.P. - cutting edge	3	4.3	-	-	-	-	-	-	-	-
P.A.W.P. - chain implement	-	-	-	-	1	0.1	2	0.6	-	-
P.A.W.P. - bar implement	-	-	-	-	1	0.2	2	0.3	-	-
Miscellaneous structural - secondary	-	-	1	0.3	-	-	-	-	-	-
Unspecified repairs	9	11.9	1	0.2	-	-	-	-	-	-
Total mechanical delays		84.6		27.0		61.2		68.8		8.2

...continued

App. I, Summary of Activities, cont'd

Activity	FB221 Feller-buncher		740A Skidder		TJ90#1 Processor		TJ90#2 Processor		LL229 Loader	
	No. occ.	Hours	No. occ.	Hours	No. occ.	Hours	No. occ.	Hours	No. occ.	Hours
SERVICE DELAYS										
Clean carrier	1	0.5	9	2.3	5	1.6	2	0.6	-	-
Power system service	1	0.7	-	-	2	0.4	1	0.5	1	0.5
Clean power system	6	3.8	3	1.0	3	1.9	1	0.4	-	-
Primary attachment service	-	-	-	-	5	1.2	-	-	-	-
Warm-up	15	3.0	23	5.9	11	3.1	10	3.5	6	1.3
Daily service	71	32.7	66	25.2	69	25.8	44	18.3	24	7.1
Fuelling	16	5.0	4	1.7	17	4.2	14	4.0	-	-
Hydraulic service	1	0.3	-	-	-	-	1	0.3	-	-
Total service delays		46.0		36.1		38.2		27.6		8.9
CLOCK NOT RUNNING										
Meals	33	15.6	45	20.4	46	18.3	34	14.1	-	-

APPENDIX II

Machine Costs

	FB221 Feller-buncher	740A Skidder	TJ90 Processor	LL229 Loader	D8 Bulldozer
OWNERSHIP COSTS					
Purchase price (P)	$391 000	$220 000	$360 000	$420 000	$100 000
Sales tax (t) %	6	6	6	6	6
Expected life (y) yr	4	4	4	6	10
Hours per year (h) h	3 000	3 000	3 000	2 000	600
Interest rate (I) %	11	11	11	11	11
Insurance rate (Ins) %	2	2	2	2	2
Purchase price after tax (Pt)	$414 460	$233 200	$381 600	$445 200	$106 000
Salvage value (S) = (0.2*Pt)	$82 892	$46 640	$76 320	$89 040	$21 200
Average investment (AVI) = (Pt + S)/2	$248 676	$139 920	$228 960	$267 120	$63 600
Loss in resale value = (Pt-S)/(y*h)	$27.63/h	$15.55/h	$25.44/h	$29.68/h	$14.13/h
Interest = (I*AVI)/h	$9.12/h	$5.13/h	$8.40/h	$14.69/h	$11.66/h
Insurance = (Ins*AVI)/h	$1.66/h	$0.93/h	$1.53/h	$2.67/h	$2.12/h
Total ownership costs	$38.41/h	$21.61/h	$35.37/h	$47.04/h	$27.91/h
OPERATING AND REPAIR COSTS					
Fuel consumption (F) L/h	25	25	25	34	45
Fuel cost (f) $/L	0.40	0.40	0.40	0.40	0.40
Operating supplies per year (O)	$1 500	$1 500	$3 000	$1 000	$500
Annual repair and maintenance (R)	$30 000	$20 000	$40 000	$18 000	$5 000
Tire/track replacement (T)	$20 000	$12 000	$12 000	$20 000	$30 000
Tire/track life (TL) h	6 000	3 000	6 000	6 000	4 000
Wages (W)	$17.73/h	$17.73/h	$17.73/h	$17.73/h	$17.73/h
Wage benefit loading (WBL) %	35	35	35	35	35
Fuel cost (FC) = (F*f)	$10.00/h	$10.00/h	$10.00/h	$13.60/h	$18.00/h
Lube & oil cost = (0.15*FC)	$1.50/h	$1.50/h	$1.50/h	$2.04/h	$2.70/h
Operating supply cost = (O/h)	$0.50/h	$0.50/h	$1.00/h	$0.50/h	$0.83/h
Repair and maintenance cost = (R/h)	$10.00/h	$6.67/h	$13.33/h	$9.00/h	$8.33/h
Tire/track cost = (T/TL)	$3.33/h	$4.00/h	$2.00/h	$3.33/h	$7.50/h
Labour cost (LC) = [W*(1+WBL/100)]	$23.94/h	$23.94/h	$23.94/h	$23.94/h	$23.94/h
Overtime = (LC*0.5/9)	$1.33/h	$1.33/h	$1.33/h	$1.33/h	$1.33/h
Total operating costs	$50.60/h	$47.94/h	$53.10/h	$53.74/h	$62.63/h
OWNERSHIP AND OPERATING COSTS	$89.01/h	$69.55/h	$88.47/h	$100.78/h	$90.54/h
Excluding interest	$79.89/h	$64.41/h	$80.07/h	$86.09/h	$78.88/h
8-hour shift cost	$639.12	$515.28	$640.56	$688.72	$631.04