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Contents

Author
Kris Kosicki,
Western Division

Productivity and cost of summer harvesting in a central Alberta mixedwood stand

Abstract

During the summer of 1999, the Forest Engineering Research Institute of Canada (FERIC) studied a roadside harvesting operation in a hardwood-dominated mixedwood stand in central Alberta. This report presents productivity and cost information on equipment used to harvest the study block.

Keywords

Harvesting systems, Felling, Skidding, Processing, Productivity, Costs, Boreal mixedwood.

Introduction

Forest management objectives and practices in western Canada are changing rapidly. New equipment and operational technologies are being developed, tested, and introduced. For their successful implementation, however, reliable information about the effectiveness and cost of the conventional and new equipment and technologies is necessary. To address this need, FERIC conducts an ongoing program in western Canada that monitors and reports on trials of harvesting systems.

FERIC observed a roadside harvesting operation in a hardwood-dominated mixedwood stand in central Alberta, with the cooperation of Alberta-Pacific Forest Industries, Inc. The purpose of the study was to determine the productivities and costs of the harvesting phases, and document soil disturbance and compaction for summer logging on sensitive soils. The harvesting operations were performed during the dry, rainless period from July to September 1999.

This report presents productivity and cost information for conventional equipment used to harvest the study block. This information will be used to evaluate alternative skidding equipment and new strategies and technologies currently studied by FERIC. Results on soil disturbance will be presented in a separate report.

Objectives

The specific objectives of the study were to:

- Determine productivity and cost for the felling, skidding, and processing phases.
- Develop productivity and cost functions for the skidding phase.
- Determine machine utilization for the study period.
- Test variability in the operator-related productivity for feller-bunchers, skidders, and delimbers.
- Test if the productivities and scheduling of the equipment resulted in a balanced harvesting system.
- Assess the potential advantages of continuous collection of shift-level data for harvesting equipment by contractors and forest companies.

Figure 1. Location of the study site.

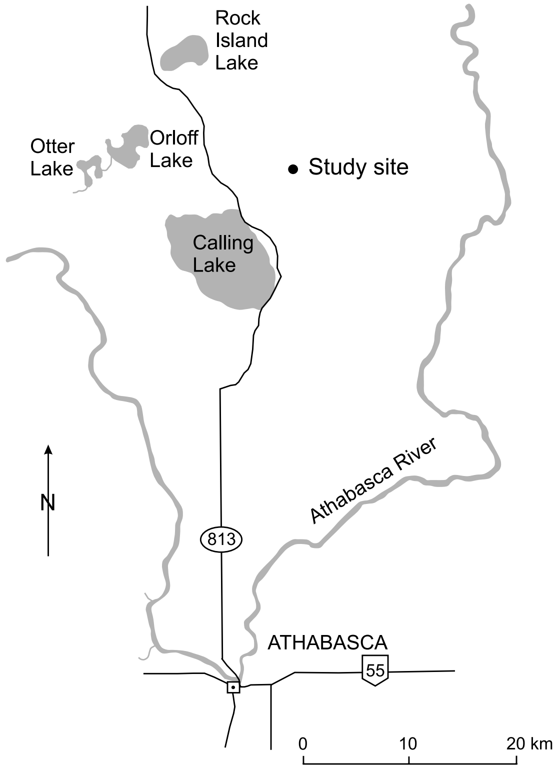

Table 1. Site and stand characteristics	
Total area (ha)	200
Prescription	LFN[a]
CPPA terrain class[b]	3.1.1.
Ecological area[c]	Boreal Mixedwood (BM)
Natural subregion[c]	Central Mixedwood
Ecosites[c]	Low-bush cranberry Aw, and dogwood Pb-Aw
Moisture regime[c]	Submesic to subhygric
Rutting and compaction hazard[c]	Medium to high
Stand composition (% by volume)	
Hardwood (trembling aspen and balsam poplar)	92
Softwood (white spruce)	8
Net merchantable volume (m^3/ha)	168
Utilization standards	
Minimum butt diameter (cm)	15
Minimum top diameter (cm)	10
Maximum stump height (cm)	30

a In the LFN (Leave For Natural) method, all regeneration will be achieved through the natural suckering process.
b Mellgren 1980.
c Beckingham and Archibald 1996.

Site & stand description

The study block monitored by FERIC was located approximately 60 km north of Athabasca (Figure 1). The block was approved for roadside harvesting and was considered suitable for summer logging with the stipulation that rain and evidence of rutting would stop skidding activities immediately. The site and stand characteristics for the block are summarized in Table 1.

Silvicultural system

The study block was harvested following the ecosystem management rules designed by Alberta-Pacific. A major aspect of ecosystem management is maintaining structural features similar to those found after a forest fire. These features include live merchantable trees of all types and ages, standing dead trees (snags), downed logs, and non-merchantable vegetation.

On the cutblock, the feller-buncher operators left clumps, single trees, and patches of non-merchantable vegetation. Clumps of different shapes and sizes (from about one buncher swath in diameter to about 1 ha) were located on steeper ground, low-lying wet areas or inoperable terrain. The clumps centred around snags, large spruce trees, natural gaps with fallen trees and other areas of dense understorey. In addition, single trees or small patches of up to three trees were left on the cutblock. These trees, at eight per hectare on average, were scattered randomly throughout the block. They included crooked or highly branched trees and some trees with well above-average diameter at breast height (dbh). All snags were left standing, except when they were within two tree lengths of a road or posed a risk to workers. All patches of non-merchantable vegetation were undisturbed during felling and skidding.

Forest Engineering Research Institute of Canada (FERIC)

Find us Online! www.feric.ca

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9
(514) 694-1140
(514) 694-4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4
(604) 228-1555
(604) 228-0999
admin@vcr.feric.ca

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System description

Harvesting operations in the study block were performed by a full-phase contractor using a fully mechanized roadside system. It consisted of two feller-bunchers; four grapple skidders; four roll stroke delimbers; and a crawler tractor for spur road construction and maintenance.[1]

Equipment was scheduled to operate 5 days per week and 11 h per shift. The two feller-bunchers worked on a double-shift basis with a four-person crew. All four skidders worked on a one-shift system. Two of them had full-time operators, and the remaining two skidders had four operators over the study period. Three of the four processors worked on a double-shift basis and one processor was operated during the day shift only, using a total of seven operators. The designated operator of the crawler tractor also operated one of the skidders when not building and maintaining roads. Access roads were built several months in advance, while in-block spurs were built concurrent with harvesting. Skidding and processing started four days after the first day of felling.

Felling

Felling started along the back boundary of the cutblock, and the feller-buncher worked back and forth parallel to the closest haul road, cutting trees but leaving clumps, single trees, and patches of dense understorey. Merchantable trees with a dbh greater than 12 cm were felled, sorted by species (hardwood and spruce), and bunched with butts facing the direction of skidding. The feller-buncher operators ensured that the butts were evenly indexed for grapple skidding.

Skidding

The skidder operator began with the bunches nearest the road. Over short distances, the skidder usually moved in reverse to the bunches but at longer distances, the operator preferred forward travel. The skidder's full payloads consisted of one to three bunches, and were decked at the road edge. The stems could be decked along almost any section and on both sides of the haul road, thus skidders moved along relatively straight routes to the closest haul road, bypassing clumps, single trees and understorey patches (Figure 2). Decks were built up by driving the loaded skidder on top of previously skidded stems (Figure 3). After decking, the operator indexed stems that protruded from the deck.

Processing

At roadside, the skidded stems were cut to length by roll stroke delimbers (Figure 4) processing stems first along one side of the road, then turning, and processing the stems on the other side of the road. The manufactured logs had a uniform length of 10 m. Larger stems were individually processed, while smaller stems often were processed together. The operator also long-butted stems with

[1] Two Timberjack 618s with Koehring saw heads, a John Deere 748G-II, a John Deere 748E, and two Timberjack 560s; two Lim-mit 2000s mounted on Komatsu Avance PC200 tracked carriers, a Lim-mit 2200 mounted on a Komatsu Avance PC220LC carrier, and a Lim-mit 2000B mounted on a Komatsu Avance PC200LC carrier; and a Caterpillar D7R crawler tractor.

Figure 2. John Deere 748G-II grapple skidder bypassing clumps and single trees.

Figure 3. Timberjack 560 grapple skidder decking skidded bunches.

Figure 4. Lim-mit 2000 roll stroke delimber on a Komatsu Avance PC200 carrier.

butt rot greater than 50% of the basal area, and cut off stem defects.

Study methods

FERIC observed the harvesting operations, collected shift-level data, conducted detailed timing of the skidding operation, and gathered information on numbers and volumes of trees felled, skidded, and processed to document productivities and machine availability and utilization.

Shift-level data on all harvesting machines were collected daily using mechanical datalogger charts[2] supplemented with written operator reports giving number of stems produced during the shift and reasons for major delays. For definitions of timing elements, see Appendix I. Net harvest volumes were obtained from Alberta-Pacific weigh scale records.

Skidding cycles were detail-timed at frequent intervals throughout the study period and divided into five timing elements: travelling unloaded; moving to load and grappling; travelling loaded; unloading; and in-cycle delays (see Appendix I for definitions). Travelling distances unloaded and loaded, number of bunches to complete a full load per cycle, and reasons for observed delays were also recorded. The butt diameters of a sample of skidded loads were scaled and recorded to determine the stem and load volumes.

The detailed-timing data were analyzed using multiple regression techniques to determine relationships between total cycle time, skidding distance, and number of bunches per load. A .05 significance level was used to test the relationship and the contribution each independent variable made to the model. The results of the regression analysis were then used to develop equations to predict delay-free cycle time and to derive skidding production functions.

Costs for the felling, skidding, and processing phases were calculated using FERIC's standard costing methods (Appendix II). New machine prices and salvage values were obtained from equipment distributors in central Alberta, and labour rates are considered representative for Alberta forestry operations.

Results and discussion

Shift-level study

A total of 94 170 stems with a net volume of 39 876 m³ consisting of 36 656 m³ hardwood (aspen and poplar) and 3 220 m³ white spruce was harvested in the study block. The shift structures, productivities and costs of the harvesting phases are summarized in Table 2.

Felling

Both feller-bunchers were scheduled to operate five, and occasionally six, days per week. The feller-bunchers worked 72 shifts and the shift lengths ranged from 5 to 16 h and averaged 11 h. Overall, the feller-buncher produced 145 stems per productive machine hour (PMH) or 61.3 m³/PMH. For the utilization of 82%, these productivities translated into 119 stems per scheduled machine hour (SMH) and 50.5 m³/SMH, respectively. The number of stems and volume per PMH agree very closely with results presented by Andersson and Evans (1996), Mellgren (1990), and Navratil et al. (1994) for feller-bunchers of the same size working in similar stand and terrain conditions. Felling cost was calculated at $2.70/m³.

[2] The logging contractor equipped all his harvesting machines with mechanical dataloggers. Dataloggers charts were submitted by operators to the contractor and used as a base for production control and payment calculations.

Table 3 presents information on hourly productivities achieved by four feller-buncher operators.[3] Although the productivities for single shifts by operator varied widely (48–236 stems/PMH), the average productivities for the entire harvesting period were in a narrower range (119–152 stems/PMH). No significant differences in average hourly productivity were found. The utilization for all feller-bunchers was similar (78–84%). Lack of significant differences in productivities and small differences in utilization indicate a similar level of the operators' working skills.

Skidding

Grapple skidders were operated in a single-shift system, five day-shifts per week, for a total of 72 shifts.[4] The shift lengths (block area clean-up shifts excluded) ranged from 3.3 to 16 h and averaged 10.9 h. Overall, the grapple-skidder productivity was 148 stems/PMH or 62.7 m³/PMH. For the utilization of 83%, these productivities translated into 123 stems/SMH and 52.1 m³/SMH, respectively. Skidding cost was calculated at $2.12/m³.

Table 4 presents information on hourly productivities achieved by six grapple skidder operators. Skidding productivities varied widely, and analysis of variance indicated significant differences in productivities between the operators. These differences may have resulted from different skidding distances (the operators did not record average skidding distances) or the operators' skills.

Processing

Delimbers were scheduled to operate five, and occasionally six, days per week, 11 h per shift. The delimbers worked 130 shifts, and the shift lengths ranged

[3] Two operators working less than 5 h were excluded from this analysis.

[4] This number includes 3.5 h spent by two skidders clearing the block area on the last day of skidding.

Table 2. Summary of shift-level study

Description	Feller-bunchers	Grapple skidders	Processors
Available shifts (no.)	82	75	156
Productive shifts (no.)	72	72	130
Non-productive shifts (no.)	10	3	26
Total productive time (PMH)	650	636	1 248
Mechanical delay time (MDH)	106	93	157
Non-mechanical delay time (NMDH)	33	37	59
Total all delays (h)	139	130	216
Total shift time (SMH)	789	766	1 464
Average shift time (h)	11.0	10.6	11.3
Utilization (PMH/SMH) (%)	82	83	85
Availability (SMH–MDH)/SMH	87	88	89
Average skidding distance	-	150	-
Productivity			
stems/PMH	145	148	75
m³/PMH	61.3	62.7	32.0
stems/SMH	119	123	64
m³/SMH	50.5	52.1	27.3
m³/11-h shift	556	573	300
Cost ($/SMH)	136.16	110.59	134.81
Unit cost ($/m³)	2.70	2.12	4.94

Table 3. Felling and bunching productivity by operator

	Operator					
Description	A	B	C	D	A,B,D	All
Productivity (stems/PMH)						
minimum	96	92	81	48	48	48
maximum	236	224	184	214	236	236
average[a]	151	151	119	152	151	145
standard deviation	39	32	29	47	39	39
Productivity (m³/PMH)	64	64	50	64	64	61
Utilization (%)	83	84	78	84	84	82

[a] No significant differences between means for operators A, B, and D at $\alpha = .05$, and between all operators at $\alpha = .01$.

Table 4. Skidding productivity by operator

	Operator						
Description	A[a]	B[a]	C	D	E	F	All
Productivity (stems/PMH)							
minimum	127	56	44	49	70	43	43
maximum	338	223	193	237	218	183	338
average[b]	204	130	98	152	159	94	148
standard deviation	59	54	45	63	42	48	65
Productivity (m³/PMH)	86	55	41	64	67	40	63
Utilization (%)	84	81	86	79	89	80	83

[a] Skidding performance of operators A and B was detail-timed.
[b] Significant differences between means for all operators.

from 4 to 14.5 h and averaged 11.3 h. Overall, the delimbers processed 75 stems/PMH or 32 m^3/PMH. For the utilization of 85%, these productivities translated into 64 stems/SMH and 27.3 m^3/SMH. Processing cost was $4.94/$m^3$. The number of stems and volume per PMH agree with results presented by Araki (1991) and Moshenko (1992) for Lim-mit delimbers.

Table 5 presents information on hourly productivities achieved by seven delimber operators. The productivities for single shifts by operator varied widely (29–125 stems/PMH). For the entire harvesting period, the productivities by operator were in a narrower range (68–79 stems/PMH). No significant differences in average hourly productivity were found. The utilization for all delimbers was similar (78–89%). Lack of significant differences in productivities and small differences in utilization indicate a similar level of the operators' working skills.

Note:
A well balanced harvesting system is achieved by selecting the appropriate numbers of machines, shifts per day, and scheduled machine hours per shift

Summary of productivities and harvesting costs

There was only a small difference in productivities of felling and skidding equipment (50.5 m^3/SMH and 52.1 m^3/SMH, respectively). However, the processing productivity of 27.3 m^3/SMH was far below these values. Despite these differences, all phases in the operation had reasonably similar average daily production (Table 6).

The overall cost for felling, skidding, and processing based on the shift-level data was $9.76/$m^3$ (Figure 5). The most expensive phase was processing ($4.94/$m^3$ and 50% of total harvesting costs).

Table 5. Processing productivity by operator

Description	Operator A [a]	B [a]	C	D	E	F	G	All
Productivity (stems/PMH)								
minimum	44	52	46	46	29	69	47	29
maximum	104	106	93	115	89	87	125	125
average[a]	69	77	71	79	68	77	69	75
standard deviation	16	13	12	21	18	4	16	15
Productivity (m^3/PMH)	29	33	30	33	29	33	29	32
Utilization (%)	89	87	78	86	88	88	82	85

[a] No significant differences between means for operators at $\alpha = .05$.

Table 6. Daily productivity of harvesting equipment

Equipment	Machines (no.)	Shifts per machine and day (no.)	Average shift time (SMH)	Productivity (m^3/SMH)	Productivity (m^3/day)
(1)	(2)	(3)	(4)	(5)	(6)[a]
Feller-buncher	2	2	11.0	50.5	2 222
Grapple skidder	4	1	10.6	52.1	2 209
Processor	3 1	2 1	11.3	27.3	2 159

[a] Daily productivity in column (6) = (2) x (3) x (4) x (5).

Detailed-timing study: grapple skidders

Two skidders, a John Deere 748G-II and a Timberjack 560, were detail-timed for 10.3 h, and the study results are summarized in Table 7.

Table 7. Summary of detailed timing for the grapple skidders

Description	Total
Productive time (min)	619
Productive machine hours (PMH)	10.3
Total cycles (no.)	160
Stems (no.)	1 920
Estimated volume (m^3)[a]	845
Average cycle time (min)	3.87
Stems per cycle	
minimum	7
maximum	25
average	12
Average load (m^3/cycle)[a]	5.28
Skidding distance (m)	
minimum	10
maximum	240
average	120
Bunches (no./cycle)	
minimum	1
maximum	3
average	1.44
Productivity	
stems/PMH	186
stems/SMH[b]	154
m^3/PMH	82
m^3/SMH[b]	68

[a] Using average volume (from stem volume sampling) of 0.44 m^3/stem.
[b] Using utilization from shift-level study of 83%.

Figure 6 presents the distribution of cycle time for the grapple skidder. "Travel loaded" was the longest element of the skidding cycle, accounting for 1.37 min/cycle (36%). Loading time was 21% of the total cycle time and depended on the number of bunches required to complete a full load. For 64% of all cycles, a full load consisted of a single bunch.

Cycle time, productivity, and cost of skidding

Multiple regression analysis was performed on 160 detail-timed skidding cycles. The analysis found a significant linear relationship between delay-free cycle time and the variables of skidding distance and number of bunches grappled to complete a full load (Equation 1, Appendix III).

Figure 7 presents predicted delay-free cycle time for the grapple skidders as a function of skidding distance and number of bunches to complete a full load. Both variables have a strong impact on cycle time. For example, cycle time increases by 1.16 min as the number of bunches necessary to complete a full cycle load increases from 1 to 3. For a skidding distance of 120 m (the average for this study), this represents a

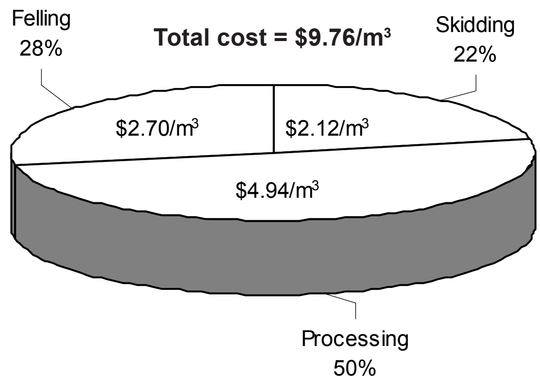

Figure 5. Distribution of harvesting costs by phase.

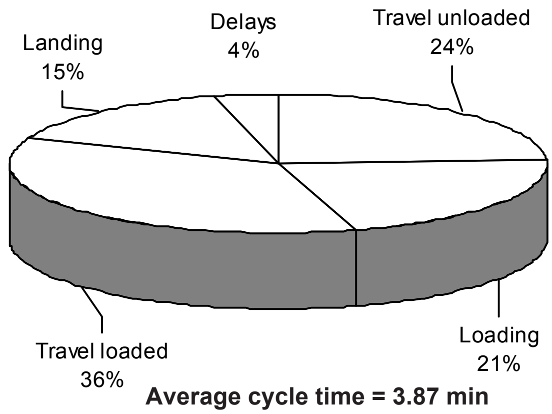

Figure 6. Distribution of cycle time for the grapple skidder.

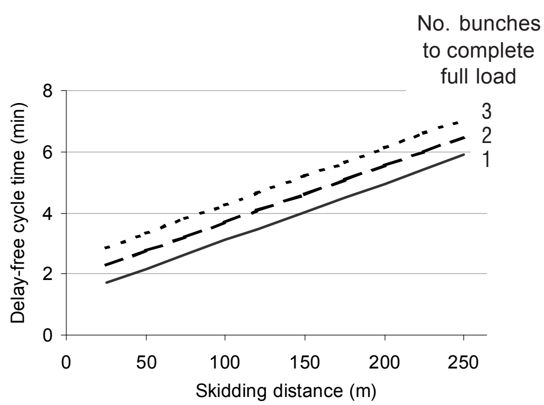

Figure 7. Predicted delay-free cycle time as a function of skidding distance and number of bunches to complete a full load.

34% increase in cycle time. The impact of the number of bunches is even greater for shorter skidding distances. For 1.44 bunches per cycle (also the average in this study), doubling skidding distance from 100 to 200 m results in a 56% increase in cycle time.

The shift-level data and detailed-timing results were combined to estimate productivity during scheduled skidding time (Equation 2, Appendix III). This can be used to predict wood flow and schedule processing and hauling activities on a shift-level basis.

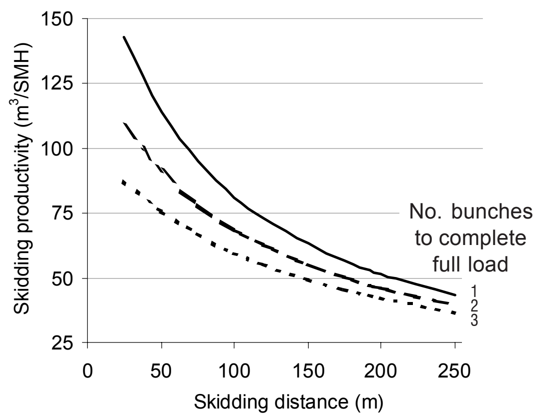

Figure 8. Predicted skidding productivity as a function of skidding distance and number of bunches to complete a full load.

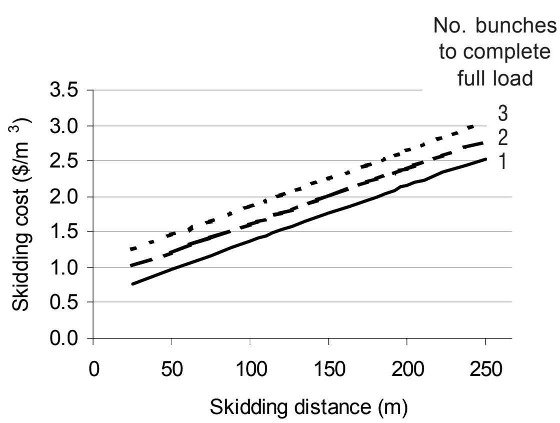

Figure 9. Predicted unit skidding cost as a function of skidding distance and number of bunces to complete a full load.

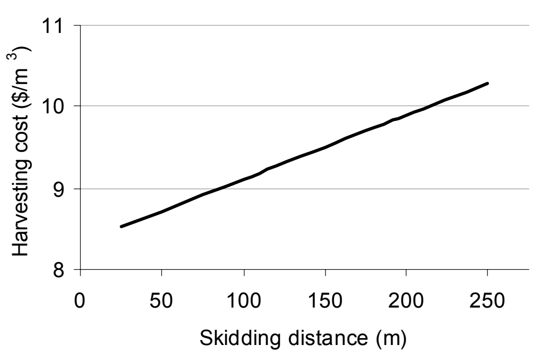

Figure 10. Harvesting cost as a function of skidding distance.

Figure 8 shows predicted skidding productivities for the grapple skidder as a function of skidding distance and number of bunches to complete a full load. Doubling skidding distance from 100 to 200 m results in a 30–37% reduction of the skidding productivity. For a skidding distance of 120 m, productivity is reduced by about 13% for each additional bunch necessary to complete a full load.

Unit skidding costs in \$/m³ were calculated using Equation 3 in Appendix III, and Figure 9 shows these costs as a function of skidding distance and number of bunches to complete a full load.

Figure 10 shows estimated unit harvesting costs[4] as a function of skidding distance. An increase in skidding distance has only moderate impact on unit harvesting cost. For example, doubling the distance from 100 to 200 m results in a 9% increase in unit costs.

Conclusions

A total of 39 876 m³ was harvested from the study block. There was only a small difference in productivities of felling and skidding equipment (50.5 and 52.1 m³/SMH, respectively). However, the processing productivity of 27.3 m³/SMH was far below these values.

For the felling and processing phases, the operator-related differences in long-term productivities were small and statistically insignificant. The utilization levels for all groups of machines were similar and varied from 82% for feller-bunchers to 85% for delimbers.

FERIC estimated the total unit costs for felling, skidding and processing at \$9.76/m³. Felling accounted for \$2.70/m³ (28% of total unit cost), skidding for \$2.12/m³ (22%), and processing for \$4.94/m³ (50%).

The skidder's cycle time was strongly correlated with skidding distances and number of bunches to complete a full load.

[4] Felling and processing costs based on shift-level studies, and skidding cost based on detailed-timing study.

The payloads averaged 1.44 bunches and 5.28 m^3 per cycle. Based on the shift level study, for an average distance of 150 m, productivity was 52 m^3/SMH at a cost of \$2.12/m^3.

The selection of the appropriate number of machines, shifts per day, and scheduled machine hours resulted in a well-balanced harvesting system without delays related to interaction between harvesting phases.

The use of dataloggers provided the contractor with valuable information on shift structure, machine productivity, frequency of delays and their reasons, and operator performance. Continuous recording, gathering, and processing of shift data can be used to generate local production tables that let the contractor determine the number of machines to perform a harvesting operation; establish, evaluate, and modify the scheduling for this operation; and calculate the overall costs.

Implementation

- To obtain accurate information on machine productivity and improve the economics of the harvesting operation, the use of mechanical or electronic dataloggers installed on harvesting equipment is recommended and encouraged.
- For operations that involve several machines and more advanced computerized management systems, second-generation electronic dataloggers (such as the MultiDAT developed by FERIC) may be useful. Some come equipped with an internal motion sensor that detects movement of the machine. On some dataloggers, the operator can enter codes on the keypad that describe the work in progress or the reason for machine downtime. A GPS receiver may be added to some dataloggers to collect positional data and determine the areas harvested or treated. Data shuttles are used to transfer the data from the datalogger to a personal computer.

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Appendix I

Description of timing elements

For shift-level studies

Mechanical delays	That part of scheduled machine time required to repair or replace parts due to failure or malfunction. It also includes daily servicing, fueling, modifications and improvements of the machine, and waiting for parts and mechanics.
Non-mechanical delays	That part of scheduled machine time during which the machine was not doing productive work for reasons other than mechanical reasons.
Productive shift	Any shift when the machine was performing a function for which it was scheduled.
Productive time	When the machine does the type of work for which it is intended. Expressed in terms of productive machine hours (PMH), including all minor delays and machine movements with duration less than 15 min/occurrence. The various activities performed by the machine during productive time are refered to as work elements.
Scheduled time	The time during which the machine was regularly scheduled to do productive work, e.g., eight or nine hours per shift, with one, two, or three shifts per day. The scheduled in-shift time, expressed in terms of scheduled machine hours (SMH), was divided into: • productive machine time (h) • mechanical delay time (h) • non-mechanical delay time (h)

For detailed timing of skidding

Delay	Begins when a productive function is interrupted and ends when a productive function is recommenced.
Landing	Begins when the load is dropped on the landing and ends when the skidder starts moving away from the deck.
Loading	Begins when the skidder stops to grapple first bunch and ends when the final load is lifted up by the grapple.
Travel loaded	Begins when the final load is lifted up by the grapple and ends when the load is dropped on the landing.
Travel unloaded	Begins when the skidder starts moving away from the deck and ends when the skidder stops to grapple first bunch.

Appendix II

Machine costs ($/scheduled machine hour) [a]

	Feller-buncher 26 000 kg	Grapple skidder 130 kW	Delimber on 125-kW carrier
OWNERSHIP COST			
Total purchase price (P) $	452 000	310 000	470 000
Expected life (Y) y	2.5	5	2.5
Expected life (H) h	10 000	10 000	10 000
Scheduled hours/year (h)=(H/Y) h	4 000	2 000	4 000
Salvage value as % of (P) (s) %	20	25	20
Interest rate (Int) %	10	10	10
Insurance rate (Ins) %	3	3	3
Salvage value (S)=((P•s)/100) $	90 400	77 500	94 000
Average investment (AVI)=((P+S)/2) $	271 200	193 750	282 000
Loss in resale value ((P-S)/H) $/h	36.16	23.25	37.60
Interest ((Int•AVI)/h) $/h	6.78	9.69	7.05
Insurance ((Ins•AVI)/h) $/h	2.03	2.91	2.12
Total ownership costs (OW) $/h	44.97	35.85	46.77
OPERATING COST			
Fuel consumption (F) L/h	30	25	25
Fuel (fc) $/L	0.45	0.45	0.45
Lube & oil as % of fuel (fp) %	15	15	15
Annual tire consumption (t) no.	0	2	0
Tire replacement (tc) $	0	2 500	0
Track & undercarriage replacement (Tc) $	25 000	0	15 000
Track & undercarriage life (Th) h	5 000	0	5 000
Lifetime repair & maintenance cost (Rp = 0.8•P) $	361 600	248 000	376 000
Shift length (sl) h	11	11	11
Operator wages (W) $/h	22.00	22.00	22.00
Wage benefit loading (WBL) %	38	38	38
Fuel (F•fc) $/h	13.50	11.25	11.25
Lube & oil ((fp/100)•(F•fc)) $/h	2.03	1.69	1.69
Tires (t•tc/h)	0	2.50	0
Track & undercarriage (Tc/Th) $/h	5.00	0	3.00
Repair & maintenance (Rp/h) $/h	36.16	24.80	37.60
Wages & benefits (W•(1+WBL/100)) $/h	30.36	30.36	30.36
Overtime (0.5W(sl-8)(1+WBL/100)/sl) $/h	4.14	4.14	4.14
Total operating costs (OP) $/h	91.19	74.74	88.04
TOTAL OWNERSHIP AND OPERATING COST (OW+OP) $/h	136.16	110.59	134.81

[a] These costs are estimated using FERIC's standard costing methodology for determining machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company studied.

Appendix III

Results of regression analysis

Equation 1: $CT = 0.649 + 0.019\ SD + 0.581\ NB$

n = 160 cycles R^2 = .808 $S.E.E.$ = .561

where:

CT	=	Delay-free cycle time (min)
SD	=	Skidding distance (m)
NB	=	Number of bunches to complete a full load
n	=	Number of cycles used in the regression analysis
R^2	=	Multiple coefficient of determination
$S.E.E.$	=	Standard error of estimate

This equation is applicable for the following ranges:

- SD: 10–240 m
- NB: 1–3 bunches/cycle

Equation 2: $$Productivity = \frac{60(CV)(U)}{CT + DT}$$

where:

Productivity	=	Predicted productivity in m^3/SMH
CV	=	Average volume per skidding cycle (m^3)
U	=	Utilization (from Table 2)
CT	=	Cycle time from Equation 1
DT	=	“In-cycle” delay of 0.15 min/cycle

Equation 3: $$Unit\ cost = \frac{HC}{Productivity}$$

where:

Unit cost	=	Estimated unit cost in \$/m^3
HC	=	Estimated machine cost in \$/SMH
Productivity	=	Predicted productivity in m^3/SMH from Equation 2