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Contents

Productivities and costs of two harvesting trials in a western Alberta riparian zone

Abstract

During the winters of 1997/98 and 1998/99, Weldwood of Canada Limited, Hinton Division conducted partial cutting trials in riparian forests adjacent to the McLeod River near Hinton, Alberta. The Forest Engineering Research Institute of Canada (FERIC) monitored the harvesting operations to determine harvesting productivities and costs, and to assess the operational suitability of using mechanized harvesting systems for partial cutting in riparian areas. Ways to improve productivity and decrease residual stand damage are suggested.

Keywords

Harvesting systems, Mechanical method, Partial cutting systems, Group selection harvesting, Modified shelterwood cutting systems, Riparian zone management, Productivity, Costs, Alberta

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Introduction

Forest management objectives and practices in western Canada are changing rapidly to place stronger emphasis on management of timber and non-timber resources in riparian ecosystems.[1] Although riparian areas cover a small percentage of the total forest land, they are vital to maintaining biodiversity, wildlife, fisheries, and water quality. Foresters recognize the productivity, uniqueness and complexity of riparian zones, and the need for development of management rules to maintain biodiversity and the overall integrity of riparian ecosystems. Because experience with riparian ecosystems is limited, research is needed to develop and examine appropriate alternative silvicultural systems and harvesting techniques, and to learn how to manage forests under these regimes.

The McLeod Alternative Silvicultural Systems Study is located on Weldwood of Canada Limited, Hinton Division's Forest Management Area (FMA) in a 300-ha riparian forest along the McLeod River. Riparian zones account for approximately 5% of the land base on Weldwood's FMA.

The overall objective of the Weldwood study was to better understand ecosystem function in riparian areas and to develop silvicultural systems for maintaining biological diversity, hydrological integrity of watershed, wildlife habitat, fisheries, and wood production. An experiment was established with two silvicultural treatments:

- group selection in a white spruce stand where 20% of the tree volume was removed in small groups of stems
- modified shelterwood in mixed stands where 50% of the volume was removed during the first entry

[1] Ecologically, riparian refers to the "area adjacent to streams, lakes and wetlands that is wet enough to develop and support natural vegetative cover distinct from the vegetation in neighboring freely drained upland sites" (Stevens et al. 1995).

Weldwood also recognized that the study would provide valuable information about the suitability of mechanized harvesting systems for partial cutting in riparian areas. Therefore, Weldwood approached FERIC to monitor the harvesting operations.

This report presents the case study results of one group selection and two modified shelterwood harvesting operations monitored by FERIC during the winters of 1997/98 and 1998/99. During the course of the harvesting operations, FERIC identified opportunities for potentially improving the operational efficiency and/or cost of partial cutting in riparian stands. The silvicultural system designs are described in two other reports (Silfor 1999, 2000).

Objectives

FERIC's objectives were to:

- Evaluate the operational aspects of the harvest.
- Determine the productivities and costs of the harvesting operations.
- Identify operational factors affecting or limiting the performance of the harvesting systems.
- Suggest ways to improve operational planning and harvesting of partial cutting prescriptions in riparian stands.

Site and stand description

FERIC monitored three study blocks which were adjacent to the McLeod River, and about 40 km east of Hinton, Alberta (Figure 1). The aerial photo (Figure 2) shows a meandering channel reach of the McLeod River and the location of the study blocks on the inactive, braided flood plain of the river. Historically, the river has migrated across this plain and the frequent cut-offs and channel deposits from lateral accretion are visible on the inside of meander bends. Shallow meander scars, tributary streams, and river terraces with flat or gently inclined surfaces dominate the flood plain.

The study blocks are within the Lower Foothills (LF) Natural Subregion (Beckingham et al. 1996). The LF subregion represents a transition from the aspen/white spruce–dominated boreal mixedwood forest to the lodgepole pine–dominated upper foothills and subalpine forests. The sites within the subregion are characterized by mixed forests of lodgepole pine *(Pinus contorta)*, aspen *(Populus tremuloides)*, and white spruce *(Picea glauca)*. Balsam poplar *(Populus balsamifera)* is also a common component of these forests especially on moist to wet sites. Black spruce *(Picea mariana)* and tamarack *(Larix laricina)* are common on wet sites.

The prevailing ecological unit in Block 600 is LF-i3.1 white spruce/horsetail community with a small pocket of LF-j1.1 black spruce–white spruce/Labrador tea/horsetail community (Beckingham et al. 1996). The LF-i horsetail ecosite is wet, nutrient rich and, due in part to its enrichment by base-rich seepage water and occasional flooding, one of the most productive ecosites in the subregion. With high water tables, wet soil conditions, and Gleysolic soils, organic matter tends to accumulate. Succession on this site is largely controlled by high soil water content. When trees are removed, the water table may rise making tree establishment difficult. Soil compaction, rutting, and windthrow hazards are high. The horsetail ecosites are considered suitable for winter harvesting only (Beckingham et al. 1996; Corns and Annas 1986).

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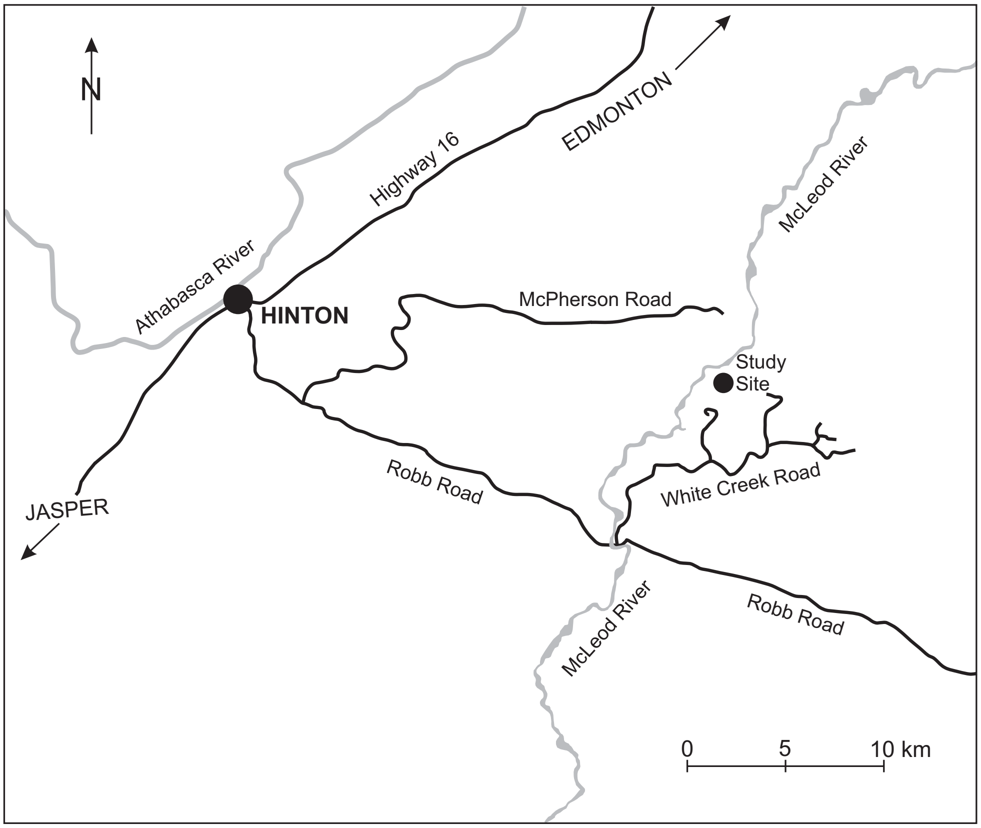


Figure 1. Location of the study site.

In Block 601, the prevailing ecological unit is LF-e low-bush cranberry ecosite. In the eastern part of the block, along the boundary with Block 600, small areas of the LF-i3.1 white spruce/horsetail community are present. The low-bush cranberry ecosites are very common in the Lower Foothills of Alberta. These ecosites have a mesic moisture regime, moderately fine to fine-textured soils or glaciolacustrine parent material, and a medium nutrient regime. Soil compaction and rutting hazards are medium. The low-bush cranberry ecosites are considered suitable for winter harvesting only.

In Block 602, longitudinal, north-south bands of three ecological units were identified. The band on the east side with the highest elevation of the bench terrace is the LF-d1.2 lodgepole pine–black spruce/Labrador tea/ feather moss plant community with a mesic moisture regime, and low to moderate compaction and rutting hazards. On the LF-d sites, all-year harvesting is possible. The middle of the block is occupied by the LF-e low-bush cranberry ecosite, and the LF-i3.1 white spruce/horsetail plant community strips are located on the west and northwest sides of the block.

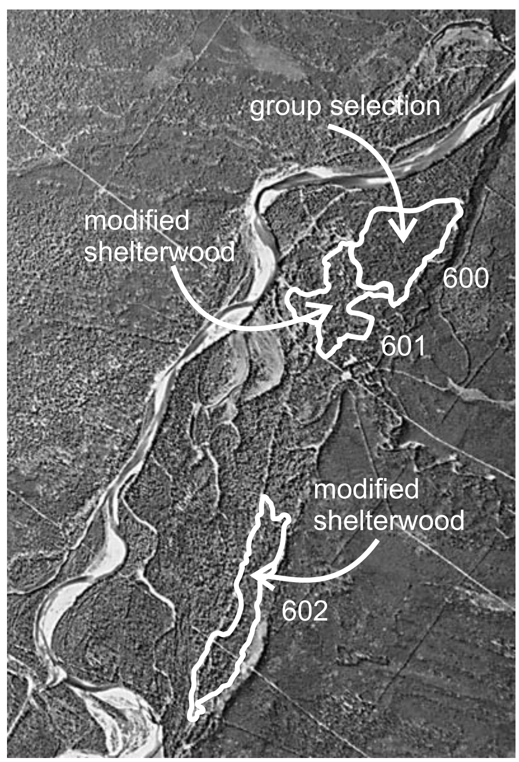


Figure 2. Aerial photo of the study site.

Table 1 summarizes the silvicultural prescriptions, ecosystem classification, and timber volumes for each case study.

Table 1. Description of sites and stands

	Block 600	Block 601	Block 602
Total area (ha)	20.3	14.8	18.2
Prescription	Group selection 40% BA removal	Modified shelterwood 50% BA removal	
Slope (%)			
Range	0–3	0–3	0–30
Average	+0	+0	+0
Terrain	even	even	even
Ecosystem [a]	LF-i3.1 & LF-j1.1	LF-e & LF-i3.1	LF-d1.2, LF-e & LF-i3.1
Stand composition (% by volume)			
White spruce	- [b]	58	27
Black spruce	- [b]	1	5
Lodgepole pine	- [b]	8	31
Aspen	- [b]	33	37
Net merchantable volume (m^3/ha) [c]	398 [d]	263/396 [e]	289/414 [e]

[a] Beckingham et al. 1996.
[b] Information is not available.
[c] Utilization criteria for merchantable volume were min. stump diameter of 15 cm and min. top diameter of 10 cm.
[d] White spruce only.
[e] Conifer only/total for all species.

Group selection system

Silvicultural prescription

During a field reconnaissance of the study site, Weldwood and Silfor (a consulting firm from Hinton) identified white spruce stands of uneven age with stand structures that were potentially suitable for silvicultural selection systems. The classical selection system in uneven-aged stands involves the removal of individual trees (single-tree selection) or small groups of neighbouring trees (group selection) from the stand. Harvesting of selected trees is performed to create a new age class with each entry; to maintain a predetermined number of trees among the immature age classes; to recover the volume in excess and mature trees; and to provide a consistent and sustained yield of desired values (Nyland 1996). In this project, a 20.3-ha white spruce stand, previously selectively harvested about 50 to 60 years ago, was selected and designated as Block 600 (Figure 2). Since Weldwood's operating guidelines prohibited manual falling, and single-tree selection with mechanical equipment was not considered feasible, a group selection system was chosen for harvesting this block. The silvicultural prescription for this treatment was designed by Silfor.

The number of trees to be cut in each diameter at breast height (dbh) class was established by comparing the dbh distribution of the existing stand with an "ideal" dbh distribution (the reverse J-curve). The diameter distributions for the existing and planned stands identified deficits in small diameter classes (5 to 25 cm) and surpluses in larger diameter classes (30 cm and greater) (Figure 3). The excess trees in the larger diameter classes were targeted to achieve a planned 40% reduction of stand basal area in the first entry. The maximum dbh of the removed trees was set at 60 cm because larger trees were to be preserved for wildlife purposes. The second entry to Block 600 is planned in ten years.

Planning and layout

The Silfor layout crew concentrated on finding and marking trees that would fall within the targeted diameter classes and could be clustered into groups. Size and shape of groups varied but attempts were made to ensure that the area of any single group did not exceed 0.1 ha in order to minimize windthrow damage to the residual stand. Each tree within the group was marked with a ribbon and measured, and group boundaries were traversed and mapped using global positioning system (GPS) technology. The process of locating, marking, and mapping was repeated until the stand was covered and approximately 10% of the cutblock area was included in well-distributed groups. Altogether, 799 trees in 62 groups were selected and marked (Figure 4). The number of trees in a group varied from 7 to 20 and averaged 13. Each group was assigned a unique number which was painted on one of the trees within the group to facilitate orientation in the stand. The groups were connected by a network of skid trails and bladed winter haul roads (Figure 5).

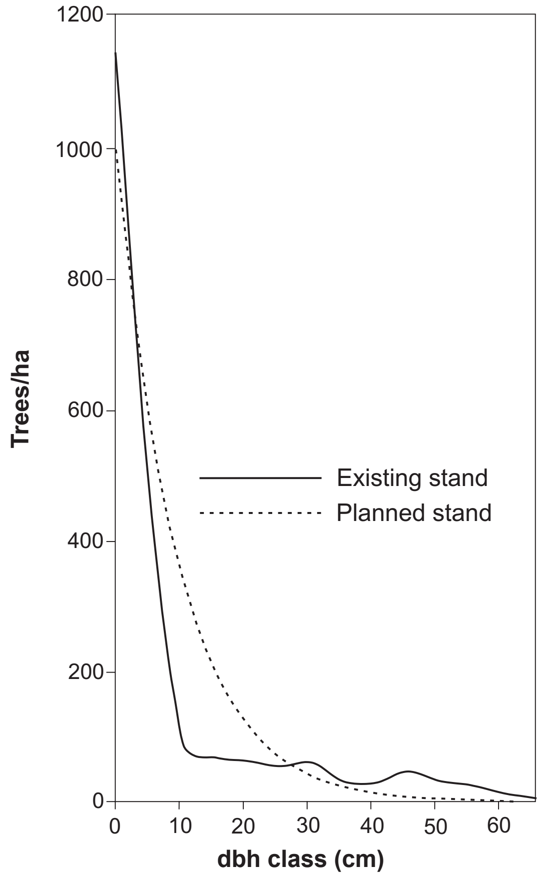


Figure 3. Distributions of dbh for existing stand and planned stand for Block 600.

Figure 4. Selected tree marked with a ribbon.

Harvesting system

A mechanized full-tree system was used to harvest Block 600. The harvesting system consisted of a Timberjack 850 feller-buncher with a Koehring 50-cm felling head, a John Deere 648E grapple skidder, and a Denharco DM3500 processor on a Komatsu PC 200 carrier. Rice Logging Co. Ltd. of Hinton, performed the skidding and processing phases, and subcontracted the falling phase to an independent contractor.

To facilitate navigating in the stand, the feller-buncher operator was provided with a GPS-generated map showing the boundaries of the block, the location of all groups and their numbers, and the skid trail network. The operator then identified the location of a group, cut the marked trees, and prepared bunches for skidding and processing (Figure 6). After all marked trees in a group were cut and bunched, the feller-buncher cut a skid trail to the next group of marked trees. Although the recommended location of the skid trails was marked with ribbons, selection of the trees to be cut was left to the discretion of the operator, who was allowed to modify the trail location to minimize damage to the residual trees. At sensitive points such as corners in groups and junctions of skid trails, the feller-buncher left rub-trees to protect the residual stand against damage by skidding. The grapple skidder extracted the bunches to skid trails and roads for processing (Figure 7). The skidder also adjusted the orientation of

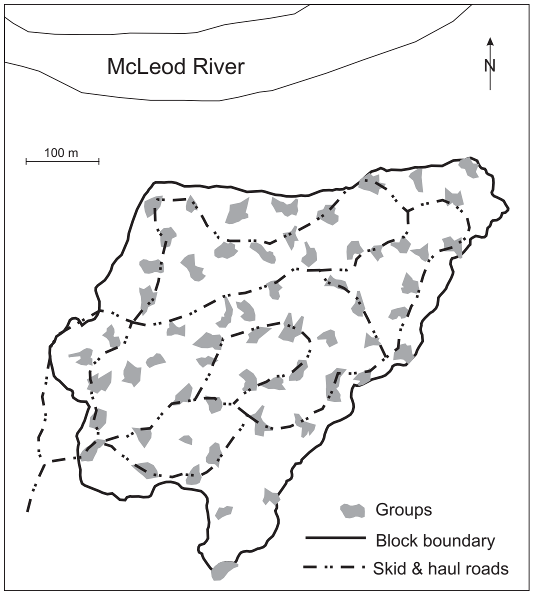


Figure 5. Location of selected groups and skid and haul roads in Block 600.

Figure 6. Timberjack 850 feller-buncher.

Figure 7. John Deere 648E grapple skidder.

Figure 8. Denharco DM3500 processor.

bunches and moved them from the shoulders to the centre of skid trails to improve the processor's performance. After processing, the skidder forwarded logs to convenient loading points on the road to facilitate the loading phase. Delimbing and processing were performed at roadside (Figure 8).

Modified shelterwood system

Silvicultural prescription

A modified shelterwood system was proposed for the mixed stands of white spruce and aspen in two cutblocks with a combined area of 33 ha (Figure 2). Block 601 contained white spruce and aspen, with minor components of lodgepole pine and black spruce, and Block 602 was composed of aspen, lodgepole pine, and white spruce.

The silvicultural system designed by Silfor for these two blocks was a modified two-pass shelterwood system. In the first pass, white spruce seed trees were selected and marked for retention, and 50% of the stand basal area was targeted for removal. Fifty-six and 24 seed trees in 35- to 50-cm dbh classes were retained in Blocks 601 and 602, respectively. In Block 602, small clearcuts were also used to harvest small patches of pure lodgepole pine. The goal of the first entry was to provide favourable conditions for natural regeneration of white spruce and pine, and to leave a residual stand of white spruce and aspen. The second entry, a removal cut with two management alternatives, was planned for 5 to 10 years after the first entry, once white spruce regeneration was secured.

Planning and layout

The work pattern for the first entry of the shelterwood system (Figure 9) was designed to remove 50% of the original basal area, using the reach of the feller-buncher's boom (about 8 m). During the first entry, the feller-buncher cut all trees in an 8-m-wide skid trail and 50% of the basal area in 4-m-wide

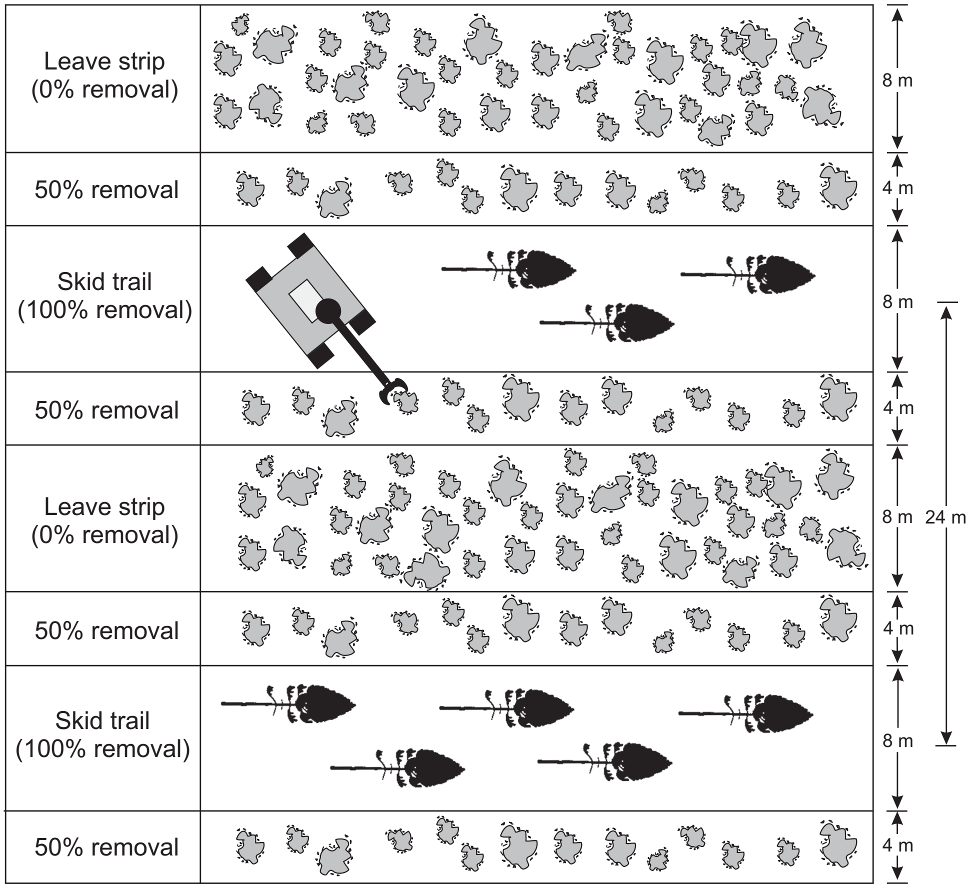


Figure 9. Harvesting pattern designed to remove 50% of the basal area.

strips on each side of the skid trail. Eight-metre-wide strips were left untreated on each side of the harvested strip; these will be harvested in the second pass of the shelterwood system. The distance from centreline to centreline of two adjacent first-pass strips was 24 m.

Figures 10 and 11 show the haul roads and skid trail patterns for Blocks 601 and 602. In Block 601, haul roads were located so that some areas were accessible from both ends of the designed skid trail network. After selecting white spruce seed trees in Blocks 601 and 602, and marking small patches of pure lodgepole pine for clearcutting in Block 602, Silfor's crew established a network of skid trails spaced 24 m apart by flagging the trail centrelines. Fifty-five and 66 skid trails were established in Blocks 601 and 602, respectively. At the beginning of several trails, trees were marked in the 50% basal area removal strips to guide the operator. After that, the selection of trees to be cut in the 4-m strips with 50% retention was left to the discretion of the feller-buncher operator. During layout, centrelines of skid trails were slightly relocated or bent where necessary to create a protective buffer between the trails and flagged seed trees. Junction angles between the haul road and skid trails were about 50°. To address wind damage, visual quality, and wildlife concerns, inside angles between the "dog-legged" skid trail sections were about 140° (Figure 11).

Harvesting system

A mechanized full-tree harvesting system with roadside processing was selected for the first entry in Blocks 601 and 602. The equipment included a Tigercat 845 feller-buncher, a John Deere 748E grapple skidder, and a Lim-mit LM2000 log processor mounted on a John Deere 690E-DL carrier. Bridge Lake Holdings Inc. of Hinton performed the falling and skidding operations, and Larouche Logging Ltd. of Edson worked on the processing phase.

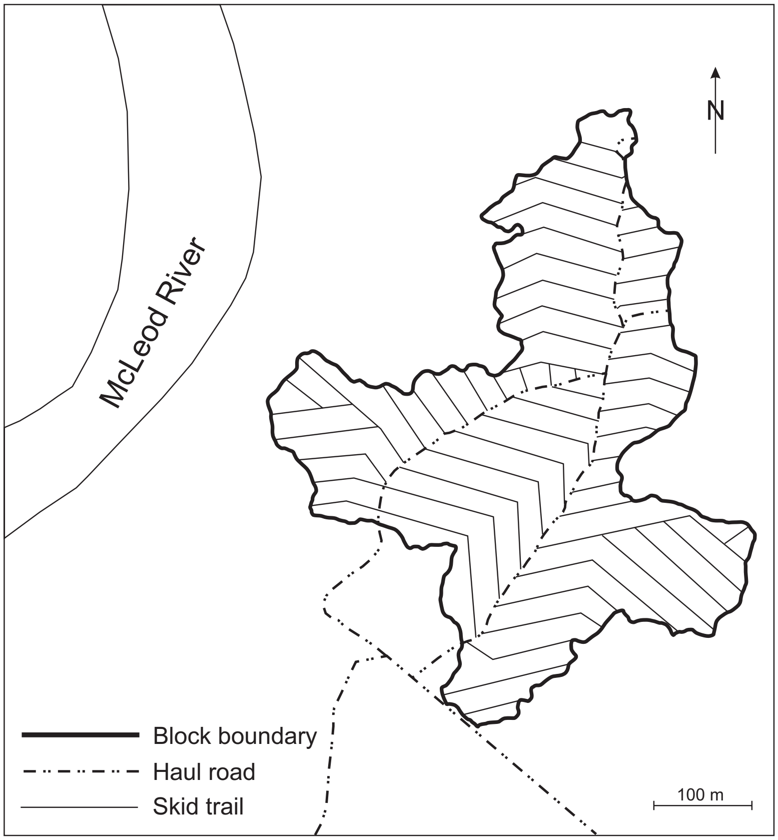


Figure 10. Layout of skid trails in Block 601.

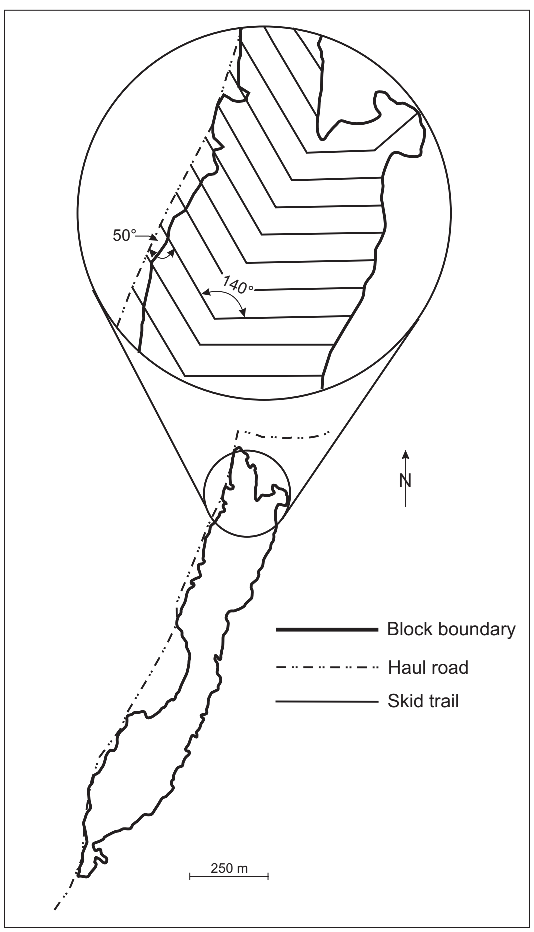


Figure 11. Layout of skid trails in Block 602.

The Tigercat 845 feller-buncher with zero tail-swing used a Koehring 50-cm disc saw (Figure 12). The feller-buncher operator was provided with a GPS-generated map showing the boundaries of the block, the skid trail network, and the location of the seed trees and lodgepole pine patches. The operator identified the skid trail junctions, clear cut an 8-m strip while removing selected trees in the 4-m strips, and prepared bunches for skidding. The bunches were extracted with the grapple skidder (Figure 13) and decked at roadside and in the ditch line, where delimbing and processing were performed (Figure 14).

Study methods

During the harvesting trials, FERIC observed the harvesting operations and collected time and production information. The field study involved collecting shift-level data, detail timing all harvesting phases, and gathering information on numbers and volumes of trees felled, skidded, and processed.

Shift-level information was collected daily from each machine operator, and included operating area, weather, production count, reasons for delays and breakdowns greater than 10 minutes, and comments on factors affecting production. Productivities in m³/scheduled machine hour (m³/SMH) were calculated for each phase based on volume harvested and time spent by each machine in the harvested block, excluding lunch time. Net harvest volumes were obtained from Weldwood's weigh scale records.

Throughout the harvesting period, FERIC performed detailed timing of skidding and processing phases, using a hand-held data logger and stopwatches, to quantify individual cycles and/or cycle elements and to describe the work patterns used in each treatment (Appendix I).

Costs for the felling, skidding, and processing phases were calculated using FERIC's standard costing method and assumptions (Appendix II). New machine prices and salvage values used in the costing procedure were obtained from equipment distributors in central Alberta, and labour rates are considered representative for Alberta forestry operations. Planning and layout costs were estimated by FERIC using information supplied by Weldwood.

Results and discussion

Group selection system – Block 600

Harvesting operations in Block 600 began on February 25, and were completed on March 6. Falling and bunching started on February 25, and continued throughout two full and four partial shifts to March 2. The processing phase extended for six productive shifts from February 28 to March 5. Skidding started on March 2, and continued throughout five productive shifts to the end of the harvesting period. All operations were conducted during the day shifts. Temperatures during the day remained below –10°C. A total volume of 1893 m³ was harvested, consisting of 1443 m³ of sawlogs and 450 m³ of pulpwood.

Planning and layout

Information on the type and amount of field work performed to prepare Block 600 for harvesting was supplied by Weldwood and is summarized in Table 2. The cost estimates by FERIC assume that all field work is done by a two-person field crew (one professional and one technical) at a cost of $660 per 8-h crew-day.

A total of 5.2 crew-h/ha was required at an estimated cost of $426/ha or $4.56/m³. The most expensive components of the layout phase were selection and marking of trees and groups ($3.87/m³ or 85% of planning and layout costs) because the process of locating, marking, and mapping had to be repeated several times until the desired distribution of groups and removal level was achieved.

Figure 12. Tigercat 845 feller-buncher.

Figure 13. John Deere 748E grapple skidder.

Figure 14. Lim-mit LM2000 log processor.

Falling

Table 3 summarizes the feller-buncher's shift-level time, productivity, and cost for the group selection treatment. Overall, the feller-buncher produced 88 stems, equivalent to 82 m³ per productive machine hour (PMH), at a cost of $2.12/m³. In terms of number of stems per PMH, this productivity agrees very closely with results presented by Mitchell (1996) and Thibodeau et al. (1996) for feller-bunchers working in small patch

Table 2. Summary of planning and layout costs: group selection

	Total	Estimated cost ($)
Total area (ha)	20.3	-
Area reconnaissance (crew days)	0.5	330
Cruising (crew days)	1.0	660
Cutblock layout		
External perimeter (crew days)	0.5	330
Groups		
No.	62	-
Crew days	5.4	3 564
Tree marking		
No.[a]	799	-
Crew days	5.7	3 762
Total layout (crew days)	13.1	8 646
Volume harvested (m^3)	1 893	-
Cost ($\$/m^3$)	4.57	-
Cost ($/ha)	426	-

[a] Excluded trees on skid trails.

Table 3. Shift-level summary for Timberjack 850 feller-buncher: group selection

	Total
Productive machine hours (PMH)	23.1
Non-mechanical delays (NMD) (h)	2.0
Scheduled machine hours (SMH) [a]	25.1
Utilization PMH/SMH (%)	92
Availability (SMH-MD)/SMH (%)	100
Volume (m^3)	1 893
Stems (no.)	2 035
Productivity	
m^3/PMH	82
m^3/SMH	75
m^3/8-h shift	603
stems/PMH	88
stems/SMH	81
stems/8-h shift	649
Cost ($\$/m^3$)	2.12

[a] Lunch times excluded.

cuts. However, the volume produced per PMH was higher in this study because the tree size was larger (0.93 m^3/tree compared to the Mitchell and Thibodeau et al. studies at 0.62 and 0.65 m^3/tree, respectively).

No mechanical delays occurred during this study, and warm-up, servicing, and maintenance were done outside of regular shift hours. However, the operator spent a significant portion of his time (5%) becoming familiar with the block's topography and with the locations of the tree groups and skid trails. Communication with other members of the harvesting crew about harvesting procedure and cooperation was the second largest non-mechanical delay.

The feller-buncher was detail-timed for 17.6 productive hours or about 70% of total scheduled machine hours. A total of 1 639 trees was felled and bunched in 1 381 cycles, averaging 1.2 trees and 0.76 min per cycle (Table 4).

Although the felling head had the ability to accumulate several trees before bunching, the operator preferred to cut and pile each tree separately, especially while felling the trees in the marked groups. This was done because of the large tree size (average 0.93 m^3/stem and maximum 3 m^3/stem) and the operator's desire to keep full control over the bunching procedure to avoid damage to residuals. When cutting skid trails, the operator accumulated an average of 1.3 trees per cycle. Protection of residuals appeared to be the primary concern for the operator because the average volume of the unmarked trees that were cut (estimated at 0.25 m^3 per tree) should have allowed him to accumulate more stems before bunching them.

To ensure good visibility, the falling operation could not start earlier than 7:30 a.m. Good visibility for the operator was essential since much of the feller-buncher work consisted of navigating within the stand and finding marked groups and trees. As well, in the darkness, the directional falling of large trees with wide crowns would be difficult and could result in serious damage to the residual trees.

Table 4. Detailed-timing summary for Timberjack 850 feller-buncher: group selection

	Total	%
Productive time		
Falling and bunching (min)	893	85
Moving without cutting (min)	67	6
Delays <10 min (min)	95	9
Total productive time (min)	1 055	100
Productive machine hours (PMH) (h)	17.6	100
Total bunches (no.) [a]	1 381	-
Total stems (no.)	1 639	-
Stems per bunch (no.)	1.2	-
Productivity		
bunches/PMH	78	-
stems/PMH	93	-

[a] Same as cycle.

The productivity and cost results demonstrated that the Timberjack 850 feller-buncher was able to work efficiently in a group-selection treatment, at least for the site and stand conditions experienced in this study. The ability of the feller-buncher to control placement of the felled trees, thus reducing damage to residual trees and enhancing skidder extraction, was an important advantage in this treatment.

Skidding

Table 5 summarizes the grapple skidder's shift-level time, productivity, and cost for the group selection treatment. During five productive shifts, only one 3-h repair of the fuel system occurred. Mechanical availability and utilization of the skidder were 93%. Servicing and warm-up were done outside of regular shift hours. Because the grapple skidder frequently changed activities and work sites, detailed timing was not performed for the skidding phase.

The main task of the John Deere 648E grapple skidder was to extract stem bunches from the group-selection openings to the main skid trails and haul roads for processing. The extracted stems were decked parallel to the trails or roads. Extraction was generally difficult and time-consuming. The maneuverability of the loaded skidder was reduced by the small opening sizes and, in some cases, by poor location and/or orientation of the bunches. In several instances, the loaded skidder had difficulty turning the extracted bunch from an opening into the skid trail because of sharp turn angles. To avoid excessive damage to the residuals, even where rub-trees were left by the feller-buncher, the skidder operator had to drop and reposition the bunch with the skidder's blade, and grapple the load again. In some cases, this procedure was repeated several times before the bunch was properly aligned to the skid trail. The grapple skidder also adjusted the orientation of bunches and moved them from the shoulders to the centre of skid trails to improve the processor's

Table 5. Shift-level summary for John Deere 648E grapple skidder: group selection

	Total
Productive machine hours (PMH)	40
Mechanical delays (MD) (h)	3
Scheduled machine hours (SMH) [a]	43
Utilization (PMH/SMH) (%)	93
Mechanical availability (SMH-MD)/SMH (%)	93
Productivity [b]	
m^3/PMH	47
m^3/SMH	44
m^3/8-h shift	352
Cost ($/$m^3$)	2.08

[a] Lunch times excluded.
[b] Calculations based on 1 893 m^3 production.

performance. Where larger openings occurred along the skid trails, the skidder also accumulated stems for more effective processing. After processing, the skidder forwarded logs to convenient loading points on the road to facilitate the loading phase. Processed and forwarded stems were decked parallel to the road.

Processing

Table 6 summarizes the processor's shift-level productivity and cost for the group selection treatment. The processor availability was 99% and utilization was 93% for the six shifts worked, and productivity and cost were 37 m³/PMH and $4.03/m³, respectively. No major breakdowns occurred during the study period.

The processor was detail-timed for 10.5 productive hours during which 520 stems were processed in 495 cycles (Table 7). Cycle elements used in the detailed timing are described in Appendix I. Almost 80% of the stems were processed as tree-length logs. Long-butting occurred in about 4% of the cycles observed during the detailed-timing study. Because long-butting accounted for only 0.7% of the total processing time, it was included in the "second log" time. Time spent rearranging log decks, moving between decks, cleaning the working area, and minor delays totalled 0.42 min/cycle for an average cycle time of 1.27 min/cycle.

The average processing time (excluding decking, moving, cleaning, and delays) of 0.85 min/cycle in this study agrees closely with the 0.78 min/cycle reported by Araki (1994) for a roadside processing operation with a Denharco DM3000 log processor. However, the average cycle time of 1.27 min in this study was significantly greater than the 0.87 min/cycle reported by Araki. The difference can be attributed mainly to much longer delay times and times for moving between relatively small bunches (average 9 stems/bunch) prepared for processing in this study.

Modified shelterwood system – Blocks 601 and 602

The modified shelterwood system study sites were harvested between February 16 and March 11, 1999. Falling and bunching began on February 16 and were completed on February 25 (8 productive shifts). Skidding began on February 19 and ended on February 28 (9 productive shifts, including one night shift). Processing took

Table 6. Shift-level summary for Denharco DM3500 processor: group selection

	Total
Productive machine hours (PMH)	51.2
Mechanical delays (MD) (h)	0.3
Non-mechanical delays (NMD) (h)	
Operational	1.4
Organizational	2.0
Total delays (h)	3.7
Scheduled machine hours (SMH) [a]	54.9
Utilization (PMH/SMH) (%)	93
Mechanical availability ((SMH-MD)/SMH) (%)	99
Stems processed (no.)	2 035
Volume produced (m³)	1 893
Productive shifts (no.)	6
Productivity [b]	
stems/PMH	40
stems/SMH	37
stems/8-h shift	296
m³/PMH	37
m³/SMH	34
m³/8-h shift	276
Cost ($/m³)	4.03

[a] Lunch times excluded.
[b] Calculations based on 1893 m³ production.

place from February 26 to March 11 (13 productive shifts). All operations, except one night shift, were conducted during the day shifts. Daytime temperatures were below –10°C, and the soil was frozen. Volumes harvested in Blocks 601 and 602 were 1641 m³ and 1988 m³, respectively, for a total of 3629 m³.

Table 7. Detailed-timing summary for Denharco DM3500 processor: group selection

	Time observed		Average time
	Total	(%)	(min/cycle)
Productive time (min)			
Processing			
Pick	123.8	20	0.25
First log	157.8	25	0.32
Second log	31.3	5	0.06
Discharge	110.2	17	0.22
Total processing	423.1	67	0.85
Deck	43.1	7	0.09
Move	73.1	12	0.15
Clean	27.4	4	0.06
Delays <10 min	61.7	10	0.12
Total productive time (min)	628.4	100	1.27
Productive machine hours (PMH)	10.5	-	-
Total processing cycles (no.)	495	-	-
Total stems (no.)	520	-	-
Productivity (stems/PMH)	50	-	-

Planning and layout

Information on the type and amount of fieldwork performed to prepare Blocks 601 and 602 for harvesting was supplied by Weldwood and is summarized in Table 8. The cost estimates by FERIC assume that all fieldwork is done by a two-person crew (one professional and one technical) at a cost of $660 per 8-h crew-day.

A total of 2.6 crew-h/ha was required at an estimated cost of $218/ha or $1.98/m³. The most expensive components of the planning and layout phase were cruising and skid trail location and marking ($0.82/m³ each).

Falling

The feller-buncher operator had good experience with all phases of mechanical harvesting and some experience of manual falling in partial cutting. Before the falling operation in Blocks 601 and 602 started, the operator was given detailed field instructions on the reasons for the treatment and its requirements.

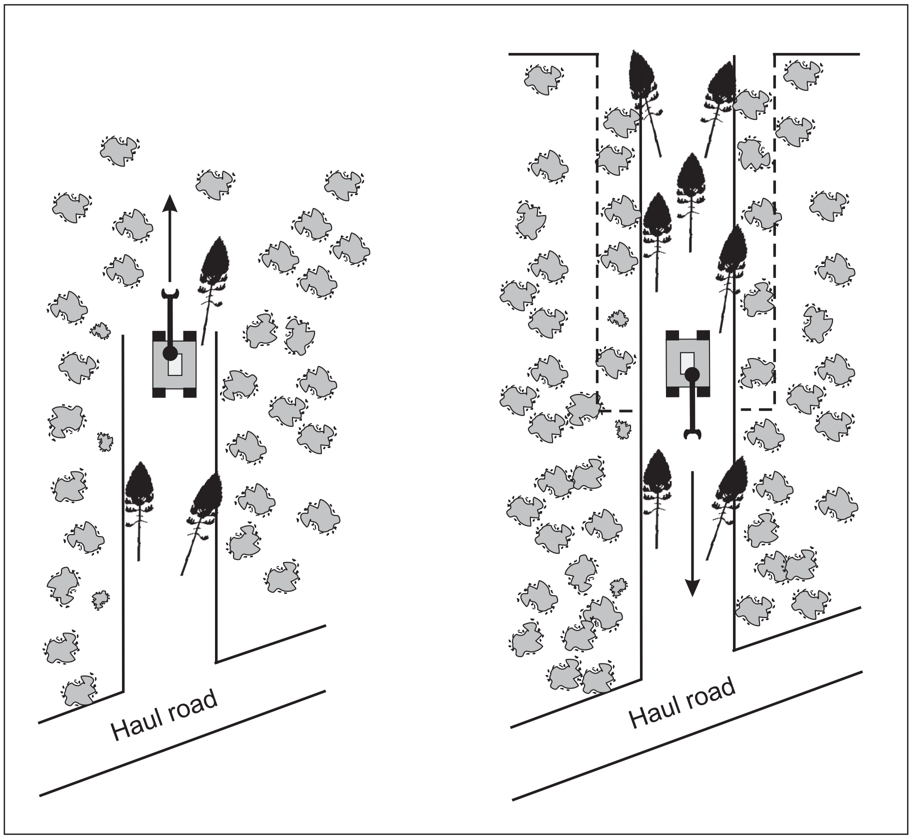
Falling began at the haul road and progressed into the stand. Flagging identified the junctions of the skid trails and their correct directions, helping the operator to maintain consistent distances between trails. While cutting the skid trails, the feller-buncher operator used three falling patterns: a "cut-up-and-cut-down" pattern, a "walk-up-and-cut-down" pattern, and a serpentine pattern.

In Block 602, with the cul-de-sac skidding trails, the operator used the "cut-up-and-cut down" pattern (Figure 15). Starting at the haul road, the feller-buncher clear cut an 8-m strip progressing toward the back of the block. The trees within the boom reach were cut and bunched to either side of the feller-buncher. To avoid damage

Table 8. Summary of planning and layout costs: modified shelterwood

	Total	Estimated cost ($)
Total area (ha)	33.0	-
Area reconnaissance (crew days)	0.5	330
Cruising (crew days)	4.5	2 970
Cutblock layout		
External perimeter (crew days)	1.4	924
Skid trails (crew days)	4.5	2 970
Total layout (crew days)	10.9	7 194
Volume harvested (m³)	3 629	-
Cost ($/m³)	1.98	-
Cost ($/ha)	218.00	-

Figure 15. Cut-up-and-cut-down pattern.



to the residual trees and cut stems, the operator placed the bunches in openings in the stand. In denser portions of the stand, the machine had to retreat before bunching the stems within the clearcut strip. Bunching in the front saved turning the boom but the stems located in the front of the feller-buncher reduced the visibility and impeded the access of the felling head to the butts of trees to be cut. After the feller-buncher reached the flagged boundary of the block, it reversed and returned to the road. The trees selected by the operator in the 4-m strips with 50% retention were cut in the front of and bunched behind the machine. Aspen trees in this strip and adjacent to the marked spruce seed-trees were left intact for additional wind protection. After arriving at the road, the feller-buncher moved to the flagged junction of the next skid trail and repeated the described activities.

In Block 601, the "cut-up-and-cut-down" pattern was used occasionally. Because the stand had lower density and a different layout of skid trails, the feller-buncher operator preferred two other patterns: a "walk-up-and-cut-down" pattern and a serpentine pattern. The "walk-up-and-cut-down" pattern was applied on the cul-de-sac skid trails, and the serpentine pattern was used only on skid trails connecting two haul roads.

In the "walk-up-and-cut-down" pattern (Figure 16), the operator skillfully maneuvered from the road between standing trees toward the back of the block. Only the trees obstructing the movement of the machine were cut and bunched in front of it. After the feller-buncher reached the boundary of the block, it reversed and moved toward the road, cutting both an 8-m-wide skid trail and a 4-m-wide strip on each side of it. The trees were cut in front of and bunched behind the machine, so that the felling head could access the butts of trees.

In the serpentine pattern (Figure 17), the feller-buncher moved between roads cutting both an 8-m-wide skid trail and 4-m-wide strips. As with the other patterns, the trees were cut in front of and bunched behind the machine. Of the three patterns, the serpentine pattern required the least travel by the feller-buncher.

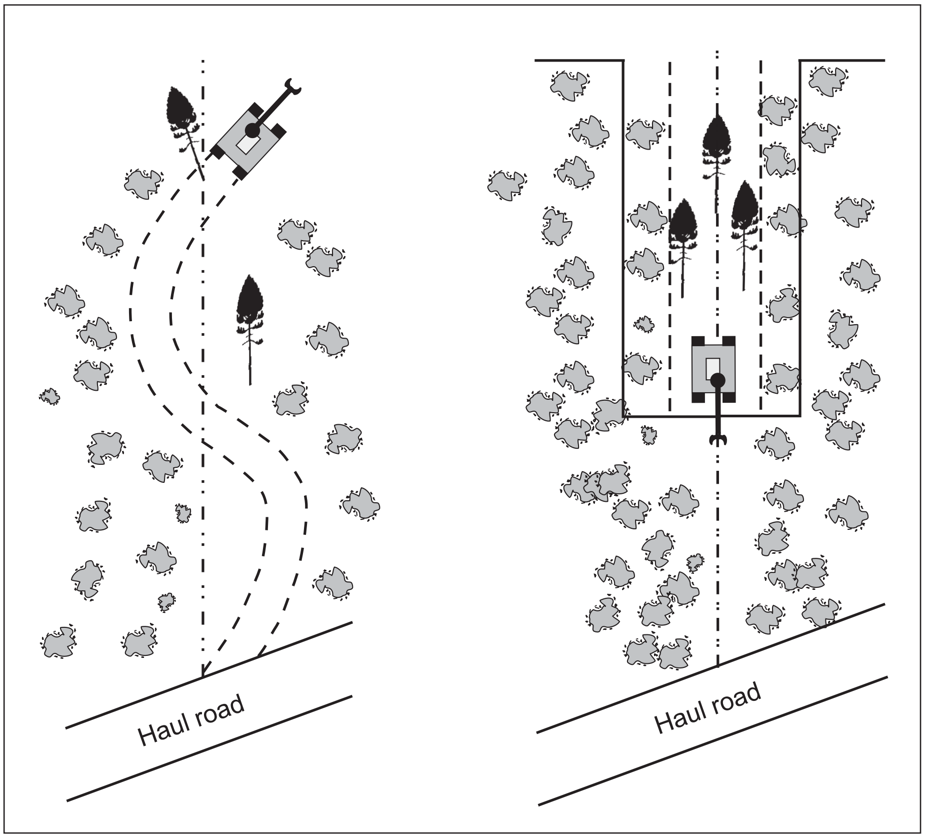


Figure 16. Walk-up-and-cut-down pattern.

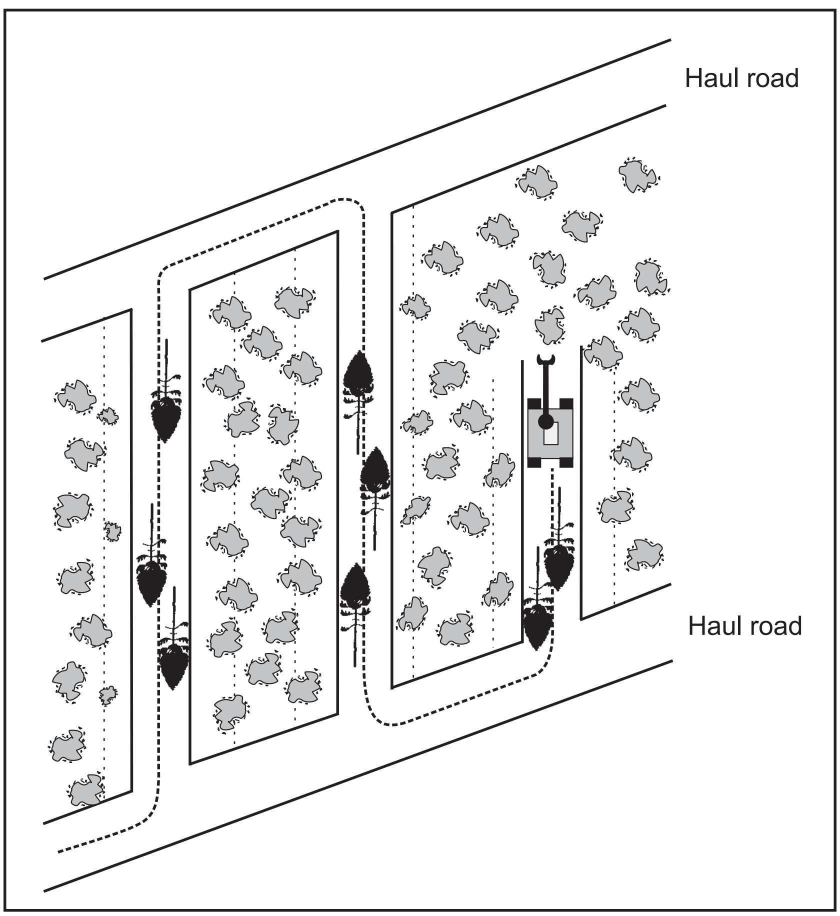


Figure 17. Serpentine pattern of skid trail cutting.

In all three patterns, the 8-m-wide trails permitted unobstructed maneuvering by the zero tail-swing feller-buncher as well as temporary bunching of the stems without substantial damage to the residual trees. To protect the flagged spruce seed-trees against potential damage during skidding, some of the adjacent trees were not cut or were felled leaving a high stump.

Table 9 summarizes the feller-buncher's shift-level time, productivity, and cost for the modified shelterwood treatment. Results for the two blocks are very similar so the data can be combined. Overall, the feller-buncher produced 136 stems and 72 m³/PMH, at a cost of $2.06/m³.

The feller-buncher's productivity in this study was slightly greater than productivities reported by Navratil et al. (1994) for feller-bunchers working in a two-stage harvesting system in mixedwood stands in northern Alberta.

Mechanical availability of the machine was very high at 97%, and utilization was 91%. The main reason for non-mechanical delays were reconnaissance and job instruction.

The feller-buncher was detail-timed for 28.3 productive hours (Table 10), during which 4 028 stems were felled in 2 870 cycles. Eighty nine percent of the time was spent in the primary tasks of falling and bunching. Productivity in bunches per PMH in Block 601 was slightly higher than in Block 602 because the average falling and bunching cycle time was shorter. Although the serpentine pattern required the least travel distances, no substantial differences in falling and bunching productivities among the cutting patterns were observed.

Table 9. Shift-level summary for Tigercat 845 feller-buncher: modified shelterwood

	Block 601	Block 602	Blocks 601 and 602
Productive machine hours (PMH)	22.73	27.57	50.30
Direct falling and bunching	22.39	27.12	49.51
Job site changes	0.34	0.45	0.79
Mechanical delays (MD) (h)	-	1.81	1.81
Non-mechanical delays (NMD) (h)	1.78	1.16	2.94
Total delays (h)	1.78	2.97	4.75
Scheduled machine hours (SMH)	24.51	30.54	55.05
Utilization (PMH/SMH) (%)	93	90	91
Availability ((SMH-MD)/SMH) (%)	100	94	97
Stems cut and bunched (no.)	2 960	3 870	6 830
Volume produced (m³)	1 641	1 988	3 629
Block area (ha)	14.8	18.2	33.0
Productive shifts (no.)	3	5	8
Avg shift time (h)	8.2	6.1	6.9
Productivity			
stems/PMH	130	140	136
stems/SMH	121	127	124
m³/PMH	72	72	72
m³/SMH	67	65	66
stems/8-h shift	966	1 016	923
m³/8-h shift	536	521	527
ha/8-h shift	4.8	4.8	4.8
Cost ($/m³)	2.03	2.09	2.06

The productivity and cost results demonstrated that the Tigercat 845 feller-buncher was able to work efficiently in a modified shelterwood treatment, for the site and stand conditions encountered in this study. The zero tail-swing and the ability of the feller-buncher to control the falling direction and location of felled stems reduced damage to the residual stand and enhanced skidding productivity.

Skidding

Skidding began at the road and progressed down the skid trails. Over short distances, the skidder usually moved in reverse. For longer distances, the operator preferred forward driving, and travel direction was usually changed close to the first loading point. There were many places along the trail where the skidder could turn around between residual trees. The payloads consisted of several bunches and included all

Table 10. Detailed-timing summary for Tigercat 845 feller-buncher: modified shelterwood

	Block 601		Block 602		Blocks 601 and 602	
	Total	(%)	Total	(%)	Total	(%)
Productive time (min)						
Falling and bunching	442	81	1 061	92	1 503	89
Moving without cutting	72	13	52	4	124	7
Relocating stems	9	2	18	2	27	2
Other productive time	10	2	16	1	26	1
Delays <10 min	9	2	6	1	15	1
Total productive time						
min	542	100	1 153	100	1 695	100
PMH	9.0	100	19.2	100	28.3	100
Total bunches (no.)	959	-	1 911	-	2 870	-
Total stems (no.)	1 215	-	2 814	-	4 028	-
Stems per bunch (no.)	1.3	-	1.5	-	1.4	-
Productivity						
bunches/PMH	107	-	100	-	101	-
stems/PMH	135	-	147	-	142	-

species. The skid trail width of 8 m and the 140° angle between sections of the trail permitted unobstructed travelling. However, in some cases this angle was about 90° to 115°, and transition from one section to another section was difficult and time consuming. Damage to the residual trees and skidded stems was quite rare along the straight sections of the trails, but did occur on these sharper corners. The junction angle between the skid trails and the haul road was 50°, and the skidder did not experience any serious difficulties while entering or leaving the road. The rub-trees left by the feller-buncher at the junction of the trail protected the residual trees against damage by the extracted loads. The stems were decked on the roadside and in the ditch line.

Table 11 presents the grapple skidder's shift-level productivity and cost for the modified shelterwood treatment. No mechanical delays occurred during the study period. Routine service and maintenance were done outside shift hours, and refuelings during the shift were shorter than 10 min. Utilization was 97% for both blocks. The main reason for non-mechanical delays was skid trail improvement.

The observed difference in productivities between Blocks 601 and 602 can be attributed to the differences in skidding distances and number of loading stops (Table 12). On Block 601, the skidder travelled only on skid trails, and the average skidding distance was 100 m. On Block 602, the skidder travelled an average of 130 m on the skid trails and 70 m on the haul road. Average numbers of loading stops per cycle on Blocks 601 and 602 were 1.70 and 2.44, respectively; fewer stops resulted in shorter loading times (1.22 min/cycle on Block 601 versus 2.73 min/cycle on Block 602).

In both blocks, except for one night shift in Block 601, skidding was conducted during the day. During the night shift, 7 cycles/SMH were produced, far below the day productivity of 13 cycles/SMH, and for this reason the night work was not continued.

A total of 236 skidding cycles was detail-timed (Table 12). In both blocks, the most time-consuming elements of the skidding cycle were loading and decking, accounting for about 54% of productive cycle time. The serpentine pattern and the "walk-up-and-cut-down" pattern applied in Block 601

Table 11. Shift-level summary for John Deere 748E grapple skidder: modified shelterwood

	Block 601	Block 602	Blocks 601 and 602
Productive machine hours (PMH)			
Skidding	29.0	49.1	78.1
Job site changes	0.3	0.3	0.6
Subtotal (PMH)	29.3	49.4	78.7
Non-mechanical delays (NMD) (h)	0.5	1.0	1.5
Scheduled machine hours (SMH)	29.8	50.4	80.2
Utilization (PMH/SMH) (%)	97	97	97
Availability (SMH-MD)/SMH (%)	100	100	100
Productive shifts (no.)	3	6	9
Volume (m^3)	1 641	1 988	3 629
Stems (no.)	2 960	3 870	6 830
Skidding cycles (no.)	335	368	703
Avg load			
stems/cycle	8.8	10.5	9.7
m^3/cycle	4.9	5.4	5.2
Productivity			
m^3/PMH	56	41	46
m^3/SMH	55	39	45
m^3/8-h shift	440	316	362
Cost ($/$m^3$)	1.92	2.69	2.35

Table 12. Detailed-timing summary for John Deere 748E grapple skidder: modified shelterwood

	Block 601		Block 602	
	Total	(%)	Total	(%)
Skidding cycle elements (min)				
Travel unloaded road	0.00	0	0.23	3
Travel unloaded skid trail	0.74	16	1.24	16
Loading	1.22	27	2.73	34
Travel loaded skid trail	0.91	20	1.23	16
Travel loaded road	0.00	0	0.35	4
Deck	1.23	27	1.52	19
Total delay-free cycle time	4.10	91	7.30	92
Delays (<10 min)	0.41	9	0.63	8
Total time per cycle	4.51	100	7.93	100
Skidding conditions				
Cycles (no.)	124	-	112	-
Avg skid distance				
road (m)	0	-	66	-
trail (m)	76	-	130	-
Avg loading stops (no.)	1.70	-	2.44	-

prepared larger and more accessible bunches for the grapple skidder, resulting in fewer loading stops and shorter loading times compared to Block 602.

Results of the multiple regression analysis and the projected productivities for the skidding operations in Blocks 601 and 602 are presented in Appendix III.

Processing

Table 13 summarizes the processor's shift-level productivity and cost for the modified shelterwood treatment. Warm-up, servicing and maintenance were done outside of regular shift hours, and no major breakdowns or delays occurred. Average productivity for Blocks 601 and 602 combined was 36 m³/PMH at a cost of $3.82/m³.

The processor was detail-timed for 9.6 h in Block 601 and 15.8 h in Block 602 (Table 14). The average productivity was 64 stems/PMH and 75 stems/PMH in Blocks 601 and 602, respectively. Proportions of time in the various activities were similar for the two blocks.

Summary of harvesting costs

Table 15 summarizes productivities in m³/PMH and estimated harvesting costs in $/m³ by phase and treatment. The table shows that costs for all phases (except for skidding) are lower for the modified shelterwood than for the group selection. Total harvesting costs for group selection were $12.80/m³, compared to $10.20/m³ for modified shelterwood. Planning and layout costs were much higher for group selection because group selection prescriptions required more intensive layout, and the costs were written off against less volume. Falling productivity in group selection was higher than in modified shelterwood because the average stem volume was larger. However, because the hourly cost of the Timberjack 850 feller-buncher in group selection was higher than the cost of the Tigercat 845 in modified

Table 13. Shift-level summary for Lim-mit LM2000 processor: modified shelterwood

	Block 601	Block 602	Blocks 601 and 602
Productive machine hours (PMH)	47.3	52.7	100.0
Mechanical delays (MD) (h)	0	1.1	1.1
Non-mechanical delays (NMD) (h)	0	0.3	0.3
Total delays (h)	0	1.4	1.4
Scheduled machine hours (SMH)	47.3	54.1	101.4
Utilization (PMH/SMH) (%)	100	97	99
Availability (SMH-MD)/SMH (%)	100	98	99
Stems processed (no.)	2 960	3 870	6 830
Volume produced (m³)	1 641	1 988	3 639
Productive shifts (no.)	7	6	13
Productivity			
stems/PMH	63	73	68
stems/SMH	63	72	67
stems/8-h shift	501	572	539
m³/PMH	35	38	36
m³/SMH	35	37	36
m³/8-h shift	277	294	287
Cost ($/m³)	3.92	3.70	3.81

Table 14. Detailed-timing summary for Lim-mit LM2000 processor: modified shelterwood

	Block 601		Block 602		Blocks 601 and 602	
	Total	(%)	Total	(%)	Total	(%)
Productive time (min)						
Mechanical delimbing and bucking	389	67	679	72	1 068	70
Rearranging deck	61	10	114	12	175	12
Clean-up working area	23	4	41	4	64	4
Manual bucking and delimbing	40	7	34	4	74	5
Calibrate lengths: check butt diameters	21	4	23	2	44	3
Moving between decks	20	3	18	2	38	2
Other	3	1	15	2	18	1
Delays <10 min	21	4	21	2	42	3
Total productive time (min)	578	100	945	100	1 523	100
Productive machine hours (PMH)	9.6	-	15.8	-	25.4	-
Total stems (no.)	620	-	1 181	-	1 801	-
Total pieces (no.)	723	-	1 356	-	2 073	-
Productivity						
stems/PMH	64	-	75	-	71	-
pieces/PMH	75	-	86	-	82	-

Table 15. Productivities and overall costs by phase and treatment

Phase	Group selection		Modified shelterwood	
	Productivity (m^3/PMH)	Cost (\$/m^3)	Productivity (m^3/PMH)	Cost (\$/m^3)
Planning and layout	-	4.57	-	1.98
Falling	82	2.12	72	2.06
Skidding	47	2.08	46	2.35
Processing	37	4.03	36	3.81
Total	-	12.80	-	10.20

shelterwood, there was no substantial difference in falling costs per cubic metre. Skidding productivities in both treatments were similar, but skidding costs were higher in modified shelterwood because the hourly cost of the grapple skidder was higher. Processing phase productivities and costs per cubic metre were almost identical.

The higher total costs in group selection than in modified shelterwood can be mainly attributed to differences in planning and layout costs. They constituted significant portions of the total operational costs: 36% in the group selection and 19% in the modified shelterwood.

Conclusions

The chosen mechanized harvesting systems were able to work efficiently in partial cutting prescriptions for the sites and stand conditions experienced in this study. The operators involved in this study were able to successfully modify their work methods to harvest group selection and modified shelterwood treatments using full-tree harvesting equipment. This demonstrates the ability of operators who have previously worked in clearcut operations to adapt to new situations, shows that specialized harvesting equipment is not required for all partial cutting operations, and indicates that the wood produced in partial cuttings could be easily integrated with that produced in clearcutting.

The partial cutting prescriptions used in this study required intensive planning and block layout which constituted a significant portion of the total operating cost. Planning and layout of high quality, however, were integral for effective partial cutting and should remain a high priority in future operations.

In both treatments, feller-buncher operators liked to follow flagged trails and the GPS-generated maps helped them navigate through the stands. The operator felt that falling productivity in the group selection would have been reduced and more residual trees would have been damaged if he had selected his own trails. In the modified shelterwood, marking of the extraction network is necessary to guide the feller-buncher operator through the stand and enable him to keep proper distances between skidding trails.

For the stand types observed in this project, the falling phase with feller-bunchers was operationally feasible and cost-efficient. The feller-buncher also provided good operator safety, control over the falling direction, and placement of stems to reduce damage to residual stands and improve skidding efficiency. Bunches of several stems (even while cutting single trees without accumulating them) permitted the use of large-capacity grapple skiddders. The size and type of the feller-buncher to be employed in selective cutting are important. The Tigercat 845 feller-buncher was small enough to work in skid trails, and the zero tail-swing enabled a 360° swing without damage to the residual trees. The disadvantage of a zero tail-swing feller-buncher is reduced stability, and the Timberjack 850 was a good choice for the group selection where the trees were considerably larger than in the modified shelterwood.

The grapple skidder operators in this study had excellent work experience in clearcutting and were able to successfully extract the stems in more challenging circumstances. The practices of keeping both falling and skidding equipment to the same trail, and of leaving rub-trees and tall stumps alongside the skid trails, were effective in protecting the residual stand.

Trail and roadside processing in group selection was difficult because of the confined space for decking and the processor's boom movements.

The scheduling of future harvesting processes in partial cutting should not cause serious problems. In both treatments, the most productive phase was falling. The feller-buncher productivity was almost twice the skidding productivity, so that the skidding phase may start shortly after falling commenced. Processing was the least productive phase of the harvesting systems and could start shortly after the skidding was initiated.

Implementation

During the observed harvesting operations, FERIC identified opportunities to improve efficiency and reduce costs.

- An early field reconnaissance of the cutblock for contractors, equipment operators, and supervisors allows the staff to analyze working conditions and establish cooperation. This may eliminate or reduce delay times resulting from insufficient knowledge of the working area.
- Marking and mapping of the groups, patches, seed trees, and extraction network in advance of the harvesting operations are necessary.
- In group selection, minor time savings in the layout phase may be realized by increasing group areas slightly and reducing the number of group openings within a given treatment block. This could potentially reduce the time to locate, mark, and survey the groups, and may improve the productivities of the falling and skidding phases.

- In the modified shelterwood, an increase in skid trail spacing (e.g., from 24 m in this study to 36 m), while maintaining the same removal intensity may result in a considerable reduction of the layout time. More information about working with a trail network based on a 36-m-wide sequence of strips can be found in Meek and Légère (1998).
- In group selection, the teardrop or diamond-shaped group areas aligned with skid trails (Figure 18) may facilitate skidding and reduce damage to residual trees by funneling the bunched stems in the direction of extraction. The junction angles of about 50° between the skid trails and the skid or haul road (Figure 19) may facilitate a smooth transition of the grapple skidder and load. Sections perpendicular to the road should be avoided since sharp curves create serious problems for the loaded grapple skidder as it leaves the skid trail and enters the road.
- Planners should examine the effectiveness of transferring processing to a landing located outside of the riparian area or to existing larger openings within a given treatment block. If the trail and roadside processing is the only option, decks of unprocessed stems should be located along the straight sections of

Figure 19. Favoured (a) and less favoured (b) connection of the group area with the road.

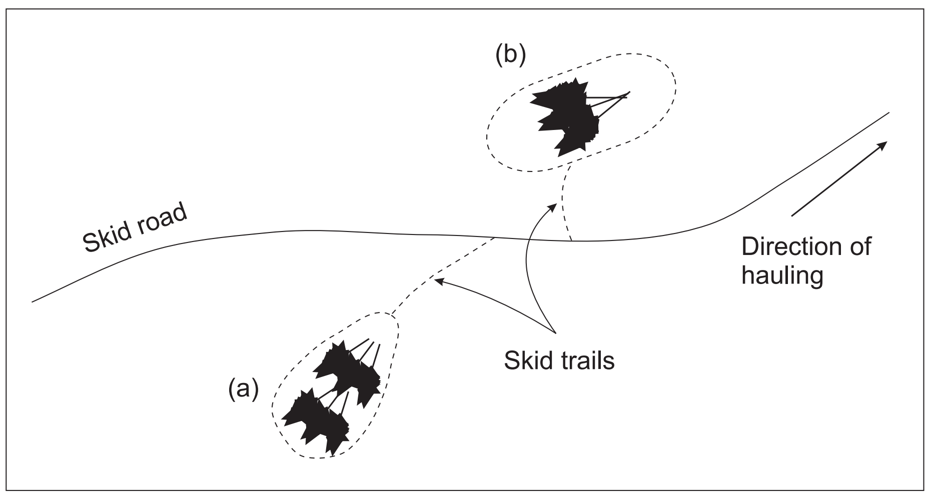
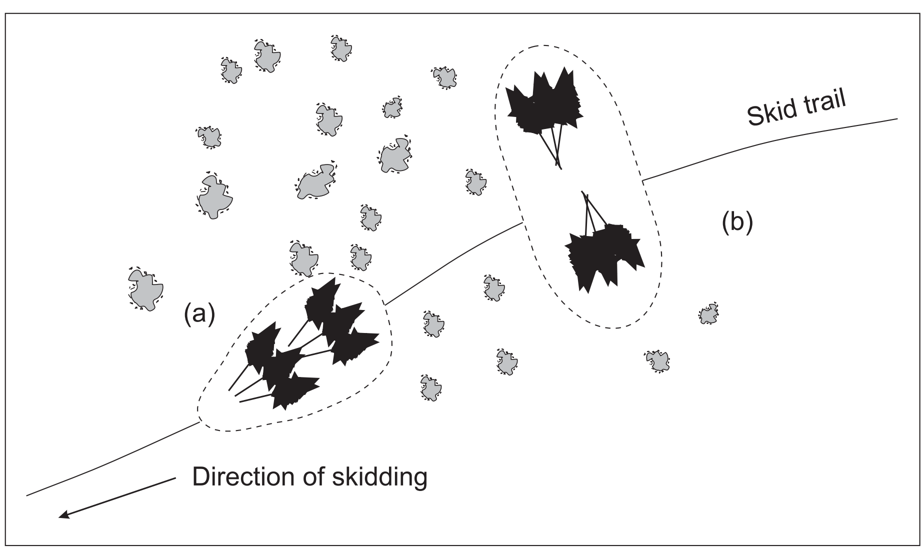


Figure 18. Favoured (a) and less favoured (b) shape of the group areas.



the trails or roads. These sections should be long enough to accommodate the aligned deck and processor with the boom retracted. The stems should be decked parallel or on a very small angle to the trail or road centreline. Decking along the winding sections, particularly in the trail or road curves, should be avoided.

- In the shelterwood system, the processor operator suggested decking the skidded stems on the road to facilitate maneuvering the boom, picking up stems for processing, and decking processed logs on the road shoulders. This recommendation, however, can be implemented only if the road can be closed to other users.

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Acknowledgements

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Appendix I

Cycle elements for detailed timing of skidding and processing phases

Skidding phase

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

Processing phase

Pick:	Begins when the butt of the previous stem is discharged and ends when the butt of the next stem is secured.
First log:	Begins when the butt is secured and ends when the first log is cut.
Second log:	Begins when the first log is cut and ends when the second log is cut.
Discharge:	Begins when the log is cut and ends when the log is placed onto the deck.
Move:	Time taken by processor to move into position to process more stems (tracks are in motion).
Clean:	Time taken to clean debris around working area.
Deck:	Time taken to rearrange stems and logs on the deck.
Delay:	Begins when a productive function is interrupted and ends when a productive function is recommenced.

Appendix II

Equipment costs [a]

	Timberjack 850 feller-buncher	John Deere 648E [b] grapple skidder	Denharco DM 3500 processor on Komatsu PC 200 carrier	Tigercat 845 feller-bucher	John Deere 748E [c] grapple skidder	Lim-mit 2000 processor on John Deere 690E-DL carrier
OWNERSHIP COSTS						
Total purchase price (P) $	540 000	250 000	470 000	440 000	310 000	470 000
Expected life (Y) y	5	5	5	5	5	5
Expected life (H) h	10 000	10 000	10 000	10 000	10 000	10 000
Scheduled h/y (h)=(H/Y) h	2 000	2 000	2 000	2 000	2 000	2 000
Salvage value as % of P (s) %	20	25	20	20	25	20
Interest rate (Int) %	10	10	10	10	10	10
Insurance rate (Ins) %	3.0	3.0	3.0	3.0	3.0	3.0
Salvage value (S)=(P•s/100) $	108 000	62 500	94 000	88 000	77 500	94 000
Average investment (AVI)=((P+S)/2) $	324 000	156 250	282 000	264 000	193 750	282 000
Loss in resale value ((P-S)/H) $/h	43.20	18.75	37.60	35.20	23.25	37.60
Interest=((Int•AVI)/h) $/h	16.20	7.81	14.10	13.20	9.69	14.10
Insurance=((Ins•AVI)/h) $/h	4.86	2.34	4.23	3.96	2.91	4.23
Total ownership costs (OW) $/h	64.26	28.90	55.93	52.36	35.85	55.93
OPERATING COSTS						
Fuel consumption (F) L/h	30	20	20	25	25	25
Fuel (fc) $/L	0.45	0.45	0.45	0.45	0.45	0.45
Lube & oil as % fuel (fp) %	20	15	20	20	15	20
Annual tire consumption (t) no.	0	2	0	0	2	0
Tire replacement (tc) $	0	2 500	0	0	2 500	0
Track & undercarriage replacement (Tc) $	30 000	0	15 000	25 000	0	15 000
Track & undercarriage life (Th) h	5 000	0	5 000	5 000	0	5 000
Annual repair and maintenance (Rp) $	86 400	40 000	75 200	70 400	49 600	75 200
Operator wages (W) h	22.00	22.00	22.00	22.00	22.00	22.00
Wage benefit loading (WBL) %	35	35	35	35	35	35
Fuel (F•fc) $/h	13.50	9.00	9.00	11.25	11.25	9.00
Lube and oil ((fp/100)•(F•fc)) $/h	2.70	1.35	1.80	2.25	1.69	7.80
Tires ((t•tc)/h) $/h	0.00	2.50	0.00	0.00	2.50	0.00
Track & undercarriage (Tc/Th) $/h	6.00	0.00	3.00	5.00	0.00	3.00
Repair and maintenance (Rp/h) $/h	43.20	20.00	37.60	35.20	24.80	37.60
Wages & benefits (W•(1+WBL/100)) $/h	29.70	29.70	29.70	29.70	29.70	29.70
Total operating costs (OP) $/h	95.10	62.55	81.10	83.40	69.94	81.10
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	159.36	91.45	137.03	135.76	105.79	137.03

[a] The costs used in the study are not the actual costs incurred by the company or contractor, and do not include indirect costs such as crew and machine transportation, overhead, profit and risk.

[b] The John Deere 648E grapple skidder is no longer commercially available. Purchase price used in the cost analysis is based on the John Deere 648G grapple skidder.

[c] The John Deere 748E grapple skidder is no longer commercially available. Purchase price used in the cost analysis is based on the John Deere 748G grapple skidder.

Appendix III

Skidding productivity of the John Deere 748E grapple skidder: modified shelterwood

Skidding cycle time

Multiple regression analysis of the detailed-timing data for Block 602 showed a significant linear relation between delay-free cycle time and operational variables of skidding distances on the road and on the skid trail, and number of loading stops (Equation 1).

$$[1]\ SCT_{602} = 1.49 + 0.0108(SDR) + 0.0227(SDT) + 0.876(NLS)$$

$n = 112 \quad R^2 = 0.66 \quad S.E.E. = 1.54$

Where:

- SCT_{602} = Delay-free skidding cycle time in Block 602 (min)
- *SDR* = Skidding distance on the road (m)
- *SDT* = Skidding distance on the skid trail (m)
- *NLS* = Number of loading stops (no.)
- *n* = Cycles used in the regression analysis (no.)
- R^2 = Multiple coefficient of determination
- *S.E.E.* = Standard error of estimate

Equation 1 is applicable for travel distances on the skid trail from 10 to 275 m; travel distances on the road from 25 to 200 m; and 2 to 6 loading stops per cycle.

For Block 601, multiple regression analysis resulted in Equation 2.

$$[2]\ SCT_{601} = 0.65 + 0.0177(SDT) + 1.244(NLS)$$

$n = 114 \quad R^2 = 0.57 \quad S.E.E. = 1.05$

Where:

- SCT_{601} = Delay-free skidding cycle time in Block 601 (min)
- *SDT* = Skidding distance on the skid trail (m)
- *NLS* = Number of loading stops (no.)
- *n* = Cycles used in the regression analysis (no.)
- R^2 = Multiple coefficient of determination
- *S.E.E.* = Standard error of estimate

Equation 2 is applicable for travel distances on the skid trail from 10 to 250 m, and 1 to 4 loading stops per cycle.

Skidding productivity

The shift-level and detailed-timing data were combined to create a model to estimate productivity during scheduled skidding time (Equation 3).

$$[3]\ SP = \frac{60\,(CV)\,(U)}{SCT + DT}$$

Where:

SP = Model productivity measured in m³/SMH (adjusted to include utilization and "in-cycle" delays)
CV = Average cycle volume (m³)
U = Utilization (%/100)
SCT = Skidding cycle time for appropriate block (Equation 1 or 2) (min)
DT = "In-cycle" delay time (min)

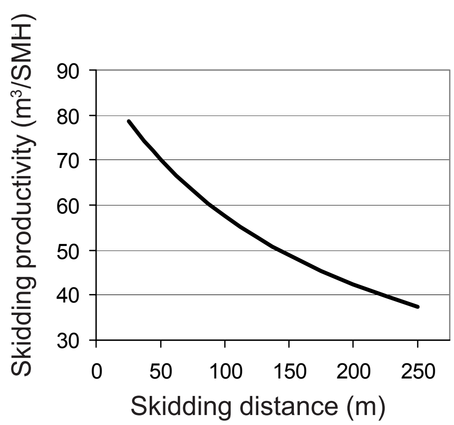
The numerical values for the components of the productivity equation were excerpted from appropriate tables and grouped in the following table.

Components of skidding productivity equation by block

Equation component	Block 601	Block 602
Average cycle volume *CV* (m^3)	4.9	5.4
Utilization *U* (%/100)	0.97	0.97
"In-cycle" delays *DT* (min)	0.41	0.63

The following graphs show the predicted skidding productivities for the road and skid trail distances observed in both blocks and appropriate data from the above table

Skidding productivity: Block 601



Skidding productivity: Block 602