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# Ground-based harvesting in a partial cutting operation in interior British Columbia

**Abstract**

The Forest Engineering Research Institute of Canada (FERIC) performed a study on three partial cutting operations in interior British Columbia, specifically small patch, patch, and shelterwood harvesting. The study provided information about the harvesting operations' productivities and costs. Results of the residual damage survey are presented. Suggestions for implementation during future partial cutting operations are given.

**Keywords**

Harvesting systems, Partial cutting, Shelterwood, Patch cut, Small patch, Visual impact, Tree damage, Productivity, Cost, Interior British Columbia.

## Introduction

Forest management objectives and practices in western Canada are continuously evolving as alternatives to conventional harvesting are explored to address non-timber resources. Altering the landscape by harvesting timber while maintaining an acceptable visual quality can be challenging. Developing techniques of harvest that meet the constraints on visual modifications are necessary if sensitive areas are to remain available to timber harvest. At the request of its members, the Forest Engineering Research Institute of Canada (FERIC) continues to conduct case study evaluations of partial cutting as it is applied to meet a variety of objectives and under different operating conditions.

This report presents the results of a small patch, patch, and shelterwood harvesting trial where partial cutting was undertaken to minimize the visual impacts of harvesting at strategic locations such as campgrounds and waterways. FERIC and Babine Forest Products Company (BFP), together with Timberline Forest Inventory Consultants, conducted the partial cutting trial under BFP's Enhanced Forest Management Pilot Project, specifically the Alternative Harvesting and Silvicultural Systems component.

## Objectives

FERIC's primary objective was to assess the economic and operational feasibility of using ground-based machinery to perform partial cutting under the conditions in this trial. Specific objectives were:

- Document productivities and costs for the falling, skidding, processing, and loading phases of harvesting for the small patch, patch, and shelterwood treatments.
- Document soil disturbance and damage to residual trees resulting from harvesting operations.
- Identify important site, stand, and other factors affecting the performance and cost of harvesting operations.

## Site description

The study sites were located approximately 40 km northeast of Burns Lake, British Columbia, within the Prince Rupert Forest Region, Lakes Forest District. The sites (two cutblocks) were located in the Babine variant of the moist cold subzone in the Sub-Boreal Spruce (SBSmc2) biogeoclimatic zone (Banner et al. 1993). Table 1 summarizes site and stand attributes for the two cutblocks.

## Silviculture prescription

The silvicultural system for Cutblock 1, adjacent to Augier Lake was a patch cut. Twenty-three patches were harvested over two years: 15 patches completed and 3 patches partly harvested (below upper spur for openings 12, 19, and 18) during year 1; and 5 patches and the remainder of the 3 patches harvested during year 2 (Figure 1). Augier Lake has an L1[1] classification and a 30-m minimum Riparian Reserve Zone.

At Cutblock 2, near Pinkut Lake, a strip shelterwood and patch cuts were prescribed. The shelterwood was harvested during year 1, and the 7 patches were harvested during year 2 (Figure 2). Cutblock 2 contains two streams, both classified as S6[2] with 20-m Riparian Management Zones.

The Visual Quality Objectives (VQO) for Cutblocks 1 and 2 are modification and partial retention, respectively.

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1 L1 classifications are lakes which are greater than 5 ha in size (BCMOF and BC Environment 1995).

2 S6 classifications are streams without fish and are not community watershed streams. S6 streams are <3 m wide (BCMOF and BC Environment 1998).

**Table 1. Site and stand attributes**

| | Augier Lake Cutblock 1 | Pinkut Lake Cutblock 2 |
|---|---|---|
| Treatment | Small patch | Patch & Shelterwood |
| Elevation range (m) | 860-980 | 990-1050 |
| Slope (%) | | |
| Range | 10-65 | 3-11 |
| Average | 20 | 7 |
| Area(ha) | | |
| Total | 91.7 | 68.7 |
| Harvested | 32.1 | 45.3[a] |
| Wildlife tree patch | 19.8 | 0.9 |
| Roads | 4.5 | 1.7 |
| Deferred/second entry | 35.3 | 38.5[b] |
| Species composition (%) | $Pl_6 S_4$ (BlAt) | $Pl_6 S_4$ (BlAtEp) & $Pl_9 S_1$ (Bl) |
| Stand parameters[c] | | |
| Stand density (stems/ha) | 357 | 343 |
| Net merchantable volume ($m^3$/ha) | 694 | 753 |
| Average net volume ($m^3$/tree) | 0.51 | 0.46 |
| Average dbh of live trees (cm) | 28 | 27 |
| Average tree height (m) | 26 | 25 |

a This area includes the entire portion of the shelterwood area (17.7 ha) which targeted a 50% basal area removal.
b Second entry includes the first-entry shelterwood area.
c Taken from operational cruise summary.

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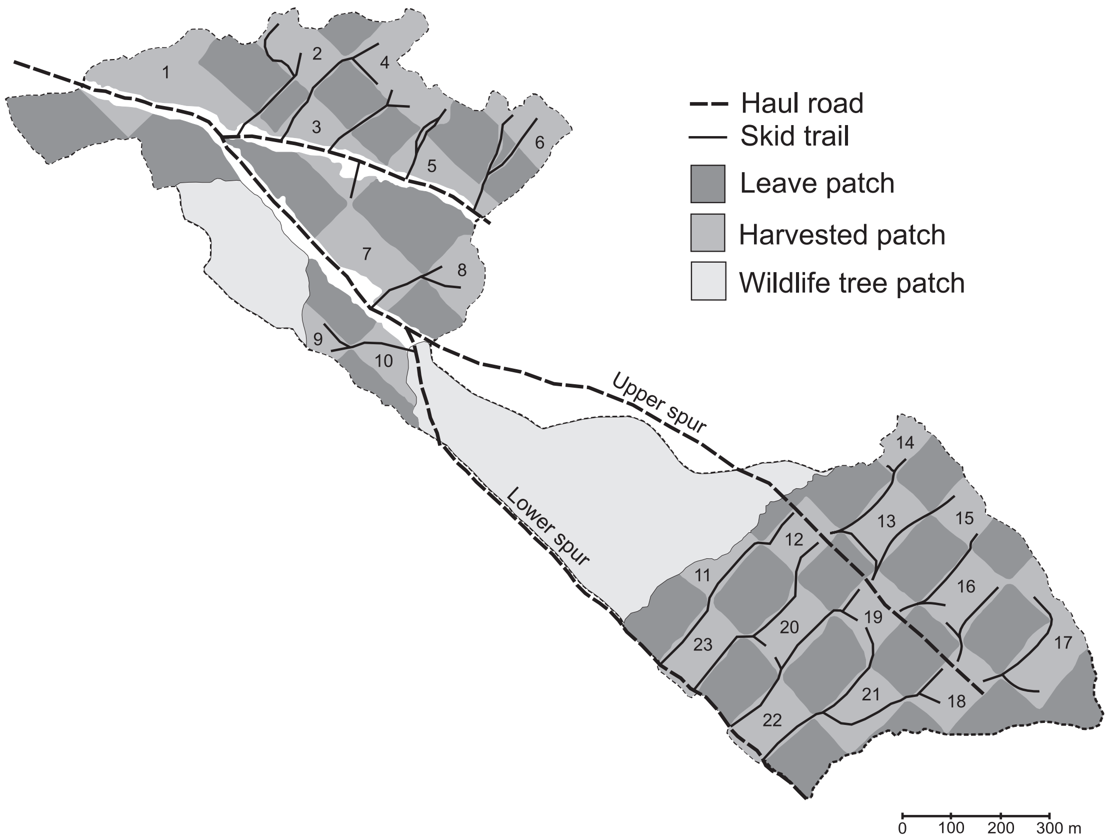


Figure 1. Cutblock 1—Small patch treatments.

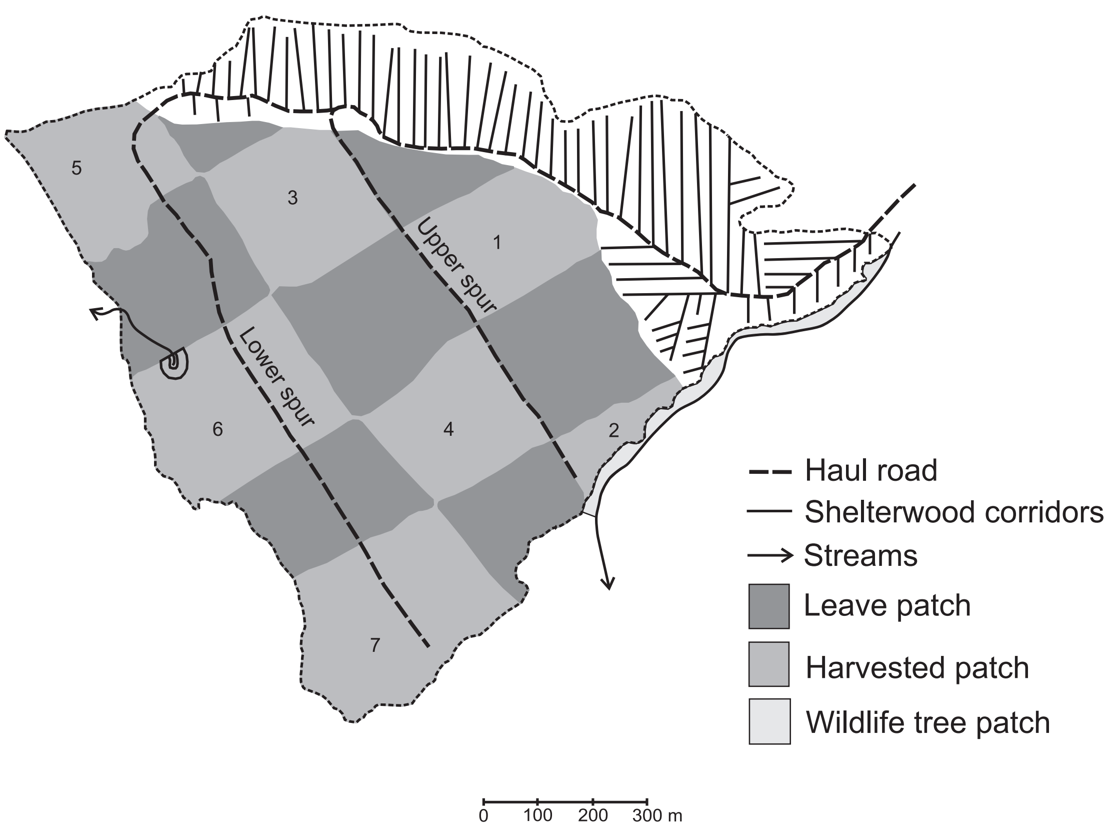


Figure 2. Cutblock 2—Patch cut and shelterwood treatments.

## Harvesting systems and equipment

The two cutblocks were harvested during two consecutive winters using different contractors at each cutblock during each year (four main contractors). Logs were sent to either BFP's mill at Burns Lake (green logs) or Decker Lake Forest Products Ltd.'s mill at Decker Lake, B.C. (dry logs). The harvesting equipment used was the typical mechanized system (Appendix I).

### Small patch treatment

The small patch harvesting was conducted by Burns Lake Native Logging Limited (Year 1) and George Zacharias Logging Ltd. (Year 2). The majority of the felling was completed by four feller-bunchers with hot-saws. Three grapple skidders and a crawler tractor skidded the stems to three stroke delimbers at roadside. A hydraulic log loader with butt-and-top grapple and a road building excavator with grapple-clam rake loaded off-highway trucks. Self-loading trucks were used for four loads during the second year of harvest.

The twenty-three patches were aligned in a checkerboard pattern with access to the adjoining patches through the corners (gates) where two patches meet. The harvested patches averaged 1.5 to 2 ha in size, and the width of the gates averaged 11 m. Access trails were built through some of the leave patches (Figure 1).

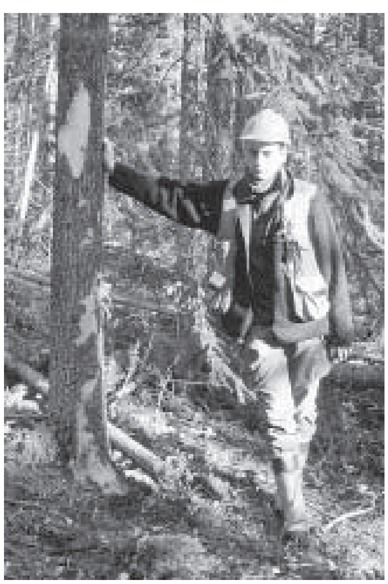

Figure 3. Damage on residual tree adjacent to a gate between patches.

The feller-bunchers placed the stems with their butts towards the haul road when cutting in the patches. However, when cutting an access trail through a leave patch, the operators would cut half of the trail width on the way to the next harvest patch, placing the stems with their tops towards the haul road. Once the next patch was felled, the operators would cut the remaining trail width on the way out, placing the stems with their butts towards the haul road.

The patches were cut in a series of swaths. The feller-bunchers cut the initial entry swath towards the back of a patch, then worked their way downhill, cutting swaths parallel to the contours. Small islands of advanced regeneration were left standing within the harvest patch. Leaving the islands did not affect productivity. Generally the slopes within the cutblock were easily navigated; however, a few short draws from 45–65% in slope, posed some concerns and minor difficulties for the operators.

The skidders were equipped with wide flotation tires wrapped with winter chains. The bunched stems were skidded full length to the roadside and decked for processing. The maximum skidding distance was 450 m, but it would have been reduced to 300 m if a proposed upper spur had been built before harvesting (Figure 1). During the second year of harvesting, this upper spur was built. Three of the 23 patches had adverse skids on slopes of 13–16%. The skidders typically travelled along the edges of the patches, perpendicular to the contours, when both loaded and unloaded. Occasionally, as the skidders approached and travelled through the gates between patches, residual trees were damaged when the machines or skidded stems rubbed against them (Figure 3).

The crawler tractor was especially useful when skidding on steeper pitches or in confined draws. The Esco swing boom gave added control of the turns as they were skidded through confined areas and between wildlife leave trees. This machine also removed snow along the roads within the cutblock.

When the decking area along the road became full at patches 22 and 23, skidded turns were placed in a second row behind the decked stems and re-skidded to roadside when room was available. Decked stems were kept to a height of 2 m (3 to 5 turns high, Figure 4).

Processing started while the skidding was in progress. The processors worked separately, typically along different spur roads. Night and weekend shifts were scheduled to provide adequate volumes for daily hauling. The processors required room to feed the full length stems through the machine cradle (Figure 5). To provide adequate space when processing below patches 22 and 23, an amendment was required to cut an additional 10 m below the road for the entire width of both patches.

During Year 1, a hydraulic log loader with a butt-and-top grapple separated dry and green logs for separate loads. Tree-length logs decked immediately next to the standing timber could not be easily swung during loading without hitting the residual stand (Figure 6). These stems had to be moved by the loader, away from the residual stand, in order to continue with loading. During Year 2 an excavator with grapple-clam rake, not a typical loading grapple, was used for loading.

Figure 4. Skidder landing turn at roadside.

Figure 5. Processor working within the patch cut treatment. An additional cut below the road gave the processor room to feed the full length stems through its cradle.

Figure 6. Loader working in patch cut treatment. Residual stand in foreground is vulnerable to stem damage during log loading.

## Patch cut treatment

The patch cut harvesting (Cutblock 2, Year 2) was conducted by Smokey Logging Ltd. using a feller-buncher with hot-saw, a grapple skidder, two stroke delimbers, a hydraulic log loader with butt-and-top grapple, off-highway logging trucks, and self-loading logging trucks.

As with the small patch treatment, these seven patch cuts were aligned in a checkerboard pattern. However, they were larger in size, averaging 4 ha, and had gate widths averaging 16 m.

The feller-buncher felled the stems with butts towards the haul road. The gentle slopes within the cutblock were easily handled by the feller-buncher and did not pose any access constraints.

The skidder was equipped with wide flotation tires wrapped with winter chains. Maximum skidding distance was 180 m, with both favourable and adverse skids. Because of the layout, skidding was not usually done through gates. The gates were utilized only a few times each when a shorter skidding distance could be achieved by skidding patches 3 and 4 to the lower spur.

As with the small patches, processing started while the falling and skidding phases were still active, the two machines worked separately, and night and weekend shifts were scheduled. Space at roadside was limited, and the machine operators were careful not to damage the trees behind the machines when processing stems on the upper spur adjacent to the leave patches.

The hydraulic log loader with a butt-and-top grapple separated dry and green logs, and loaded off-highway trucks. Self-loading trucks loaded right-of-way wood.

## Shelterwood treatment

The shelterwood harvesting (Cutblock 2, Year 1) was conducted by Klinger Enterprises Ltd. using two feller-processor heads mounted on tracked carriers, a grapple skidder, a crawler tractor (for road building and maintenance), and self-loading trucks. The crew was not experienced in shelterwood harvesting methods.

The feller-processors cut 65 corridors through the stand, at 23 m spacing. The average width of the clear-felled corridors was 7 m. Each corridor was thinned on either side to a depth of 4.5 m. An unharvested strip 7 m wide was left between corridors (Figure 7). These unharvested strips will be clear-felled and used as the skid corridors during the second entry. Shelterwood corridor widths were intentionally kept narrow to address the overall visual objectives for the area.

When harvesting began, the operators attempted to fall and process the stems within the corridors. However, the limited space prevented efficient processing (Figure 8). Instead, the felled stems were bunched and eventually skidded to roadside and processed there. After the corridor wood was felled and skidded, the feller-processors felled and bunched the partially cut (thinned) area on either side of the corridors.

To help train the operators on appropriate leave tree density, crown class, and species, the leave trees in the first few corridors were marked with spray paint. Pine trees showing good form and vigour were targeted for retention, while spruce, subalpine fir and

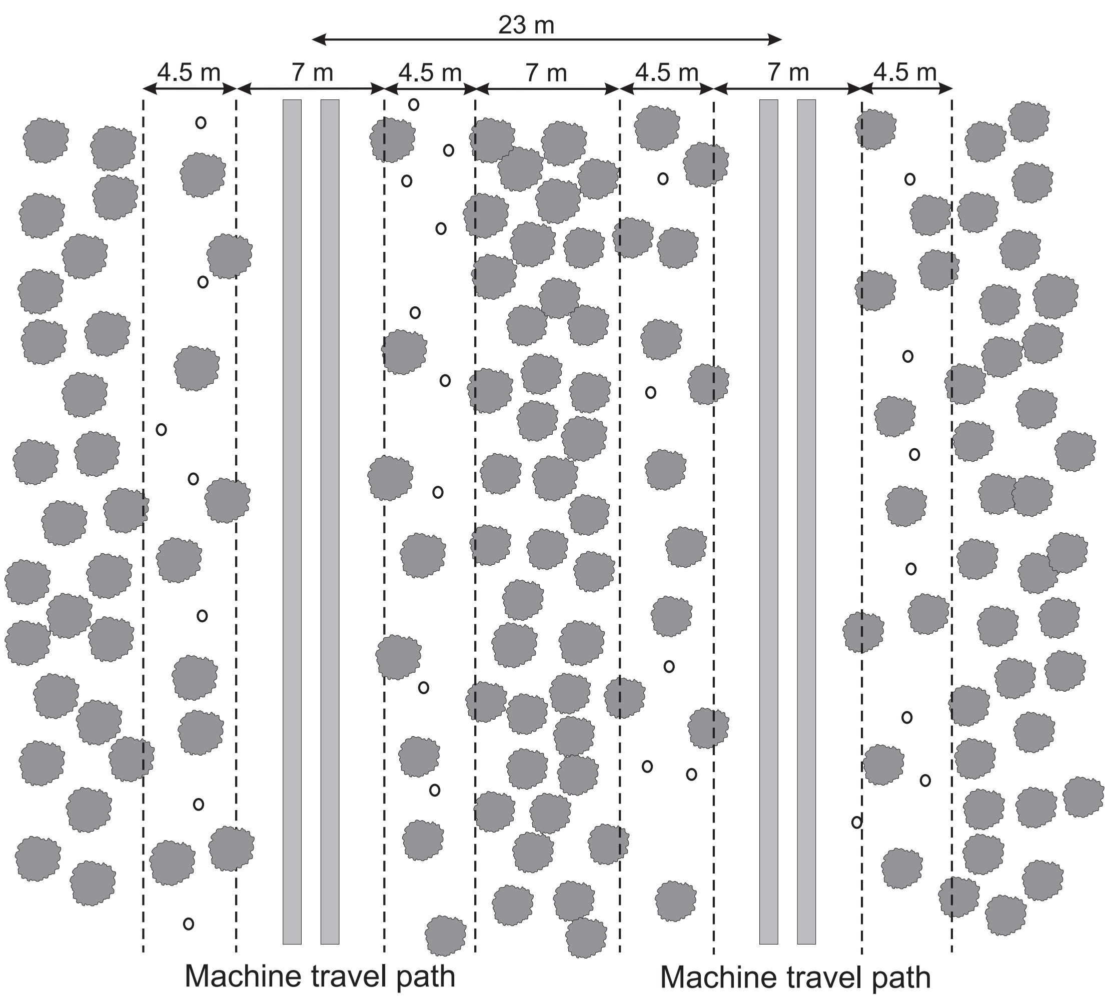


Figure 7. Corridor spacing in the shelterwood.

co-dominant, intermediate, and suppressed pine were targeted for removal. The target stand structure was executed within the thinning areas only. The corridors were cut fairly straight and spaced consistently, but in one corridor, a bend was required to avoid a draw (Figure 9). Approximately 70% of the harvested volume came from the corridor wood, and the remaining 30% from the thinning area.

Because the skidder could not turn around in the corridors, it reversed into them. Skidding the turns out onto the haul road was generally efficient, but more difficult where the road and corridor were at right angles to one another (Figure 10).

When enough wood was decked along the roadside, the feller-processors processed the stems before continuing to fall. The self-loading trucks could then load and haul logs while the harvesting continued.

## Study methods

Harvesting productivities and costs were determined using shift-level and detailed-timing study methods. Shift-level information was collected for the falling, skidding, processing and loading (not including self-loading logging trucks) phases. BFP supplied harvest volumes, expressed in $m^3$, based on its scale. All phases were detail-timed throughout the study and variables influencing system productivity were observed and recorded. Weather conditions were recorded for each day of harvesting. Hourly machine costs were calculated using FERIC's standard machine costing methodology (Appendix II) and 2000 Industrial Wood and Allied Workers of Canada (IWA) labour rates.

Following harvesting, the cutblocks were surveyed for residual stand damage. The shelterwood was surveyed by sampling 26 of the corridors along their entire lengths. The height, length, and width of scar; whether the scar penetrated the cambium; and species and diameter of damaged tree were recorded.

Figure 8. Feller-processor working within narrow corridor.

Figure 9. Shelterwood treatment unit showing a bend in the corridor.

Figure 10. Skidder repositioning stems from a corridor which approached the road at a right angle.

The small patch and patch treatment units were surveyed for damage to the residual trees at the gates, using the same criteria as in the shelterwood. Perimeter damage of the openings was considered minimal, and no formal survey was conducted, although observed damage was recorded.

The main timber extraction routes were surveyed in the small patch and shelterwood treatment units. Within the larger patch treatment, the skidder operator used dispersed skidding.

## Results and discussion

### Shift-level study

Table 2 summarizes the shift-level results by treatment and phase. Scheduled machine hours (SMH) are composed of productive machine hours (PMH) and non-productive time (mechanical, non-mechanical, servicing and other downtime). Events of non-productive time greater than 15 minutes in duration are excluded from productive time.

Table 3 shows the productivities for the phases of the harvesting operation. Falling and processing production per PMH was similar for the small patch and patch cut treatments. However, the skidding productivities for these two treatments were different at 37.5 $m^3$ and 69.5 $m^3$/PMH for the small patch and patch cut treatments, respectively. This difference is likely due to the longer skidding distance (no upper spur built during first year of harvest), and the additional skidding that was required at roadside in the small patch treatment. To maintain a balanced system in the patch cut treatment, the feller-buncher worked 6 shifts/week, and the skidder worked 5 shifts/week.

**Table 2. Shift level summary by treatment and phase**

| | Small patch | | | | Patch | | | | Shelterwood | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Falling | Skidding | Processing | Loading | Falling | Skidding | Processing | Loading | Falling & processing | Skidding |
| Scheduled shifts (no.) | 31.5 | 37 | 37 | 12 | 19 | 15 | 26 | 8 | 17 | 8 [a] |
| Scheduled machine time (h) | 254.8 | 332.8 | 339.9 | 128.8 | 188.0 | 130.2 | 255.9 | 86.3 | 170.5 | 39.3 |
| Average shift length (h) | 8.1 | 9.0 | 9.2 | 10.7 | 9.9 | 8.7 | 9.8 | 10.8 | 10.0 | 4.9 [a] |
| Mechanical delays (h) | 8.4 | 10.2 | 14.8 | 0.7 | 5.5 | 2.0 | 8.6 | 0.0 | 4.2 | 0.0 |
| Non-mechanical delays (h) | 4.2 | 5.8 | 7.2 | 4.0 | 0.0 | 1.3 | 1.3 | 0.3 | 1.5 | 0.0 |
| Service and other (h) | 19.3 | 20.2 | 19.0 | 4.9 | 23.3 | 13.7 | 16.9 | 4.0 | 16.0 | 2.1 |
| Productive machine time (h) | 222.9 | 296.6 | 299.0 | 119.2 | 159.2 | 113.2 | 229.1 | 82.0 | 148.8 | 37.2 |
| Availability (%) [b] | 97 | 97 | 96 | 99 | 97 | 98 | 97 | 100 | 97 | 100 |
| Utilization (%) [c] | 87 | 89 | 88 | 93 | 85 | 87 | 90 | 95 | 87 | 95 |

[a] Represents partial skidding shifts, operator spent remainder of the time building the road and removing snow using a crawler tractor.

[b] Availability shows the proportion of scheduled time outside of mechanical delay time, and therefore the time the machine was available to perform productive functions.

[c] Utilization shows the proportion of scheduled time spent performing productive functions.

**Table 3. Summary of productivities and costs by treatment**

| | Small patch | | | | Patch | | | | Shelterwood | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Falling | Skidding | Processing | Loading | Falling | Skidding | Processing | Loading | Falling & processing | Skidding |
| Scheduled machine time (h) | 254.8 | 332.8 | 339.9 | 128.8 | 188.0 | 130.2 | 255.9 | 86.3 | 170.5 | 39.3 |
| Productive machine time (h) | 222.9 | 296.6 | 299.0 | 119.2 | 159.2 | 113.2 | 229.1 | 82.0 | 148.8 | 37.2 |
| Volume attributed to phase ($m^3$) [a] | 11 117 | 11 117 | 11 117 | 10 892 | 7 868 | 7 868 | 8 540 | 8 073 | 1 665 | 1 665 |
| Productivity | | | | | | | | | | |
| $m^3$/SMH | 43.6 | 33.4 | 32.7 | 84.6 | 41.9 | 60.4 | 33.4 | 93.5 | 9.8 | 42.4 |
| $m^3$/PMH | 49.9 | 37.5 | 37.2 | 91.4 | 49.4 | 69.5 | 37.3 | 98.5 | 11.2 | 44.8 |
| $m^3$/average shift | 353 | 301 | 301 | 905 | 414 | 526 | 327 | 1 010 | 98 | 208 |
| $/$m^3$ | 3.44 | 3.11 | 3.36 | 1.92 | 3.73 | 1.70 | 3.29 | 1.73 | 12.98 | 2.21 |
| % of total cost | 29 | 26 | 29 | 16 | 36 | 16 | 31 | 17 | 85 | 15 |
| $/$m^3$ | 11.83 | | | | 10.45 | | | | | |
| $/$m^3$ (without loading) | 9.91 | | | | 8.72 | | | | 15.19 | |

[a] Differences in volume are due to loads loaded by self-loading trucks and/or right-of-way volumes (and times) excluded from falling and skidding phases.

When productivity is recalculated to combine the falling and processing phases, the small patch and patch cut treatments produced an average of 21 $m^3$/PMH compared to 11.2 $m^3$ for the shelterwood treatment. Lower productivity can be expected when working in narrow corridors, falling stems in standing trees, and double handling the stems for processing.

The patch cut treatment had the lowest cost for logs on the truck at \$10.45/$m^3$ (Table 3). The small patch treatment was 13% higher, attributable to the higher skidding costs associated with this treatment. The shelterwood had the highest cost at \$15.19/$m^3$, on the landing and excluding loading. When the small patch and patch treatments are presented with loading costs removed, the shelterwood treatment cost 53 and 74% more than the small patch and patch treatments, respectively.

Total harvesting costs for the small patch and patch treatments are comparable to those found by Henderson (2001) and Mitchell (1996). Henderson reports that low ground-pressure skidders (Caterpillar D5H TSK and FMG Timberjack 933C clambunk) harvesting 23–28 ha clearcuts of similar stand density and volume, using a feller-buncher with disk saw and stroker delimbers, had an average cost of \$10.63/$m^3$ processed at roadside. For 1.0-ha small patch treatments with a slightly higher piece size, using a feller-buncher with disk saw, rubber-tired grapple skidders, and stroker delimbers, Mitchell reports an average cost of \$8.54/$m^3$ processed at roadside.

## Detailed timing

Detailed-timing of the falling entailed counting the number of windfelled or merchantable stems cut and handled over a period of time (Table 4).

When the individual skidding machines are examined, the John Deere 748G no. 2 is shown to have the largest average volume per turn (Table 5). The crawler tractor was used for the longest skidding distance of 485 m.

Table 6 presents detailed-timing data for the skidding within the small patch treatment for each tier of patches. As the machines travelled further from the road, their turn

**Table 4. Summary of detailed timing for felling (small patch and patch treatment treatments) and felling and partial processing (shelterwood treatment)**

| Machine | Sample (PMH) | Merchantable stems (no.) | Windfelled stems (no.) | Stems cut and handled (range) (no./PMH) |
|---|---|---|---|---|
| Small patch treatment | | | | |
| Timbco T430 | 5.80 | 619 | 21 | 110 (67–139) |
| Case 1187C no. 1 | 0.38 | 58 | 0 | 153 (no range) |
| Case 1187C no. 2 | 2.13 | 253 | 2 | 120 (100–128) |
| Koehring 628 | 2.10 | 375 | 13 | 185 (126–235) |
| All machines | 10.42 | 1305 | 36 | 129 |
| Patch treatment | | | | |
| Timberjack 628 | 8.35 | 1314 | 72 | 166 (110–232) |
| Shelterwood treatment [a] | | | | |
| Caterpillar 315L no. 1 | 3.64 | 253 | 3 | 70 (46–106) |
| Caterpillar 315L no. 2 | 3.75 | 260 | 0 | 69 (63–90) |
| All machines | 7.39 | 513 | 3 | 70 |

[a] The falling productivity for the shelterwood represents trees which were felled, partially de-limbed, occasionally topped, and bunched within the corridors.

**Table 5. Detailed timing for skidding by individual machine and treatment**

| Machine | Average and range of skidding distances (m) | Average and range of stems/turn (no.) | Average and range of turn time (min) | Average and range of turn volume ($m^3$) [a] |
|---|---|---|---|---|
| Small patch treatment | | | | |
| John Deere 648G | 137 (20–390) | 9.9 (5–23) | 6.0 (1.9–18.1) | 5.0 (2.6–11.7) |
| John Deere 748G no. 1 | 149 (15–400) | 9.3 (5–15) | 7.4 (0.8–15.4) | 4.7 (2.6–7.7) |
| John Deere 748G no. 2 | 185 (70–365) | 16.2 (10–24) | 7.1 (2.9–13.1) | 8.3 (5.1–12.2) |
| Caterpillar D5H | 147 (30–485) | 8.5 (4–13) | 5.7 (1.7–16.4) | 4.3 (2.0–6.6) |
| Patch treatment | | | | |
| John Deere 748G | 84 (5–200) | 11.2 (1–28) | 3.6 (0.4–7.3) | 5.2 (0.5–12.9) |
| Shelterwood treament | | | | |
| John Deere 648G | 90 (20–225) | 8.2 (6–15) | 4.6 (1.1–10.5) | 3.8 (2.8–6.9) |

[a] Volume per turn is calculated using the average net volume per tree from the operational cruise summary.

**Table 6. Detailed timing for skidding by patch tier in the small patch treatment**

| Tier | Distance (m) | Average stems/turn (no.) [a] | Average turn time (min) [a] | Average ($m^3$/turn) [a, b] |
|---|---|---|---|---|
| 1 | 15–150 | 9.8 / 8.2 | 4.7 / 3.5 | 5.0 / 4.2 |
| 2 | 150–300 | 13.0 / 8.2 | 7.4 / 5.1 | 6.6 / 4.2 |
| 3 | 300–485 | 12.4 / 9.7 | 11.2 / 10.6 | 6.3 / 4.9 |

[a] The first numbers refer to the rubber-tired skidders combined, and the second number refers to the Caterpillar crawler tractor.
[b] Volume per turn is calculated using the average net volume per tree from the operational cruise summary.

size tended to increase. The Caterpillar crawler tractor had a consistently faster turn time, for all tiers, than all the rubber-tired skidders combined.

The detailed timing for the processing is shown in Table 7. Within the small patch and patch cutting treatments, the stroke delimber produced from one to two stems per minute. The feller-processors produced from 1.5 to 3 stems per minute but some delimbing had been done during falling.

Timing of the loading with the butt-and-top loader showed that the time to load a truck averaged 28 minutes. Dry loads took longer to load and contained more pieces than the green loads. Typical green loads contained an average of 115 pieces, and dry loads contained 155. For comparison, a self-loading logging truck averaged 74 minutes to load itself.

## Residual tree damage

The residual stand damage surveys are summarized in Table 8. All the treatment units are being managed for re-entry within 15–20 years in a short-term retention management regime (regime A[3], BCMOF and BC Environment 1997). Unacceptable damage for residual trees varies by tree species. For pine, unacceptable damage includes a wound that girdles more than half of the stem circumference. For spruce and true fir, it includes a wound that girdles more than one-third of the stem, a gouge, or a wound on a supporting root within 1 m of the stem. A wound is defined as an injury that removes bark and cambium from the tree but does not penetrate into the sapwood. A gouge is

[3] Regime A (short-term retention): stand will be re-entered for a final harvest within 20 years. Stands managed under this regime can withstand considerable damage, regardless of species (possible exception of deciduous). The remaining stand will be removed before pathogens can cause significant decay. Some incipient stain is likely to occur, but serious loss of volume or quality is not likely. Stands managed for short-term retention can withstand more damage without decay pathogens causing a serious loss of volume or quality than stands with longer-term management objectives.

defined as penetrating into the sapwood or deeper.

Of the trees damaged in the small patch, 17% of them had unacceptable damage. An additional 38 trees from the perimeter of the openings sustained damage, and these had an average wound area of 175 $cm^2$ (one tree deemed to have unacceptable damage).

The gates at the patch treatment unit had less damage than those at the small-patch treatment. The four gates at the patch treatment were used rarely and were wider, reducing the residual tree damage. No perimeter damage was noted.

The shelterwood treatment had an average wound area of 23.7 $cm^2/m$ of corridor length, and an average gouge area of 2.9 $cm^2/m$. This damage produced 3 unacceptable crop trees of the 447 damaged trees surveyed. Zeglen (1997) notes that the amount of wounding increases with increasing size of equipment and repeated entry through the stand.

Expressed as occurrence per deferred harvest area, for the small-patch treatment, 2.6 trees/ha were damaged with 0.3 trees/ha deemed to be unacceptable crop trees. The

**Table 7. Detailed-timing for processing by treatment**

| Processing method | Average no. stems processed/PMH | Range of stems processed/PMH |
|---|---|---|
| Small patch treatment | | |
| Stroke delimber | 92.1 | 60.0–103.3 |
| Patch treatment | | |
| Stroke delimber | 110.0 | 60.0–122.4 |
| Shelterwood treatment [a] | | |
| Feller-processor head | 158.4 | 92.0–177.8 |

[a] Stems sampled were partially delimbed, and occasionally topped during the shelterwood falling.

**Table 8. Summary of damage to residual crop trees including both gates (small patch and patch cuts) and corridors (shelterwood)**

| | Small patch | Patch | Shelterwood |
|---|---|---|---|
| Damaged trees surveyed (no.) | 54 | 1 | 447 |
| Gates (corridors) | | | |
| Avg. gate (corridor) width (m) | 10.9 | 16.1 | 7.1 |
| Gates (corridors) surveyed (no.) | 31 | 4 | 26 |
| Surveyed gates (corridors) with damage (no.) | 27 | 1 | 26 |
| Total length of surveyed corridors (m) | - | - | 3600 |
| Length/surveyed corridors (m) | - | - | 35-237 |
| Avg. dbh of damaged trees (cm) | 29 | 35 | 25 |
| Avg. wound height above the ground (cm) | 101 | 59 | 152 |
| Avg. area/wound ($cm^2$) | 242 | 92 | 104 |
| Avg. wound area/damaged tree ($cm^2$) | 662 | 184 | 206 |
| Avg. wounds/tree (no.) | 2.7 | 2.0 | 2.0 |
| Avg. wound area/m of corridor ($cm^2$) | - | - | 23.7 |
| Avg. gouge area/m of corridor ($cm^2$) | - | - | 2.9 |
| Trees with gouge(s) (no.) | 21 | 0 | 108 |
| Trees with a wound > 400 $cm^2$ (m) [a] | 20 | 0 | 41 |
| Trees with broken tops (no.) [a] | 2 | 0 | 4 |
| Unacceptable damage: [b] | | | |
| Trees (no.) | pine:0, spruce:9 | pine:0, spruce:0 | pine:1, spruce:2 |
| Damaged trees with unacceptable damage (%) | 17 | 0 | 1 |

[a] Relevant data for longer-term management objectives.
[b] Based on B.C. FPC classification for tree species and short-term retention management objective.

patch treatment has <0.1 tree/ha damaged with no trees deemed unacceptable. Assuming the shelterwood treatment has a deferred area of approximately 8.5 ha, 52.6 trees/ha are damaged with 0.4 trees/ha deemed to be unacceptable.

### Visual objectives

Applying the alternative harvest and silvicultural systems on these visually constrained areas was an effective means of accessing the timber supply. Visible disturbance levels for both cutblocks are <1%, below maximum acceptable VQO levels within a modification (Cutblock 1) or partial retention (Cutblock 2) landscape polygon.[4]

### Soil conditions

Winter harvesting on a layer of snow over frozen ground protected the soil from detrimental disturbance. During the first year of harvesting, minimum temperatures averaged -18 °C (-9 to -36.5 °C), and maximum temperatures averaged -0.5 °C (9.5 to -6.5 °C), with a total of 20 cm of snow falling on a base of approximately 35 cm. During the second year of harvesting, minimum temperatures averaged -16.5 °C (-4 to - 27.5 °C), and maximum temperatures averaged -3.5 °C (3 to -11 °C) and a total of 29 cm of snow fell on a base of approximately 45 cm. Main timber extraction routes were used in the small patch and shelterwood treatments. These skidding trails are not considered disturbed by Forest Practices Code Standards (BCMOF and BC Environment 2001). No detrimental soil disturbance was noted within the patch treatments.

## Conclusions

Three ground-based partial cutting treatments—small patch, patch, and shelterwood—were monitored using shift-level and detailed-timing study methods during two winters. The contractors used their standard array of mechanized harvesting equipment. The operators at the shelterwood harvesting unit had no previous experience with this type of treatment, but all operators were experienced in clear felling. The small patch, patch, and shelterwood treatments had costs of $9.91/m$^3$, $8.72/m$^3$ and $15.19/m$^3$ respectively, including falling, skidding, and processing. When loading is included, the small patch and patch treatments had costs of $11.82/m$^3$ and $10.45/m$^3$, respectively. Self-loading trucks were used at the shelterwood, and were not monitored.

Falling productivity was similar for the small patch and patch treatments (49.9 and 49.4 m$^3$/PMH, respectively) but considerably lower for the shelterwood (11.2 m$^3$/PMH, including processing). Processing productivity was also similar for the two patch treatments (37.2 m$^3$/PMH for small patch and 37.3 m$^3$ for patch). Skidding productivity was much higher for the patch treatment than the small patch (69.5 and 37.5 m$^3$/PMH, respectively) with 44.8 m$^3$/PMH for the shelterwood treatment.

Detailed timing of the falling at the small patch treatment showed an average of 129 stems cut and handled/PMH and 166 stems cut and handled/PMH for the patch cut. The shelterwood treatment unit included some processing and occasional topping with the falling, giving an average of 70 stems/PMH.

Detailed timing of the skidding at the small patch treatment showed that as the machines moved further from the road, and travelled through the gates between patches, both turn time and turn volume increased. The crawler tractor had consistently faster turn times for all tiers, but also had a smaller turn volume than the rubber-tired skidders. In the patch treatment, the skidder typically did not travel through the gates while skidding, and had an average turn time of 3.6 minutes for distances ranging from 5 to 200 m.

[4] Dusty Meierhofer, Silviculture/Engineering Department Manager, Timberline Forest Inventory Consultants Ltd., Prince George, B.C., personnal communication, February 2002.

Stroke delimbers processed 60 to 122 stems/PMH while the feller-processors processed 92 to 178 stems/PMH, at roadside.

Residual damage surveys for the small patch and patch treatment units focused on the residual trees at the gates between openings. The gates within the patch treatment were wider and infrequently used, and trees adjacent to them had considerably less damage than trees at the gates in the small patch treatment. Although numerous trees surveyed in the shelterwood showed damage, when these trees are classified under the short-term retention management regime, only a low percentage were unacceptable crop trees. Unacceptable damage for the small patch treatment showed a total of 9 spruce trees (0.3 trees/ha of residual stand), while the shelterwood had one pine and two spruce trees (0.4 trees/ha). The patch treatment had no trees deemed unacceptable as future crop trees.

Winter harvesting protected the soil from detrimental disturbance. The temperature during harvesting was typically well below 0°C, and the ground was covered with snow.

## Implementation

During the study, FERIC identified conditions for successful and efficient use of partial cutting operations:

- Label patches, gates and trails with numbers and letters on logging plan maps to simplify machine allocation and improve safety.
- Protect gate trees with plastic barrels, matting or tires if the trees are to be retained. Alternatively, gate trees could be left as rub trees and removed at the end of harvesting, or they may be kept as wildlife trees. If the gate is wide enough, the logs may be skidded through the gate without damaging the adjacent trees.
- Shelterwood corridors do not have to be straight when using a ground-based system although bends must be gradual in order to avoid damage to edge trees. Bends can be added to avoid obstacles and difficult ground.
- If the shelterwood corridors had been wider (9 m instead of 7 m), it would have been possible to process within the corridors and re-handling at roadside would have been eliminated. As well, the machines could have travelled on a brush mat, perhaps protecting the soil and residual tree roots.
- Within the shelterwood, an appropriate corridor width may lessen residual tree damage and/or allow the thinning cut to be done concurrent with the corridor cut.
- Specifying the harvesting machine type and size at the engineering/layout stage would ensure an appropriate corridor width is designed for shelterwood harvesting.
- Skidding production is improved and damage to residual trees is reduced if corridors are at 45–65 degrees to the haul road. Where corridors must enter at 90 degrees, flaring of the corridor may be useful to help land the turn onto the haul road.
- When it is necessary to deck tree-length logs immediately adjacent to the standing trees, cutting a flare from the residual stand will facilitate loading the logs and reduce tree damage.
- Leaving advanced regeneration islands within the openings can help achieve visual quality and biodiversity objectives without hindering harvesting production.

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# Appendix I

## Machine descriptions

| Year 1 | Small patch treatment | Shelterwood treatment |
|---|---|---|
| Falling | • Timbco T430 Hydo Buncher with 56-cm Quadco cutting head, approx. width: 3 m<br>• Two Case 1187Cs with 51-cm Harricana cutting heads, approx. reach: 7.5 m, approx. width: 3.4 m<br>• Case 1187C with Lokomo cone saw | • 2 Caterpillar 315 with Log Log Max 5000 feller-processor heads, max. diameter cut: 51 cm, approx. reach 7.75 , approx. reach 2.7 m |
| Skidding | • John Deere 648G rubber-tired skidder and grapple, approx. width: 3.5 m<br>• John Deere 748G rubber-tired skidder and grapple, approx. width: 3.2 m<br>• Caterpillar D5H TSK crawler tractor with Esco swing boom and grapple, approx. width: 2.8 m | • John Deere 648G rubber-tire skidder and grapple, approx, witdth: 3.8 m |
| Processing | • 2 John Deere 690 ELC with Denis strokers | • same as falling |
| Loading | • Caterpillar 300 Log Loader with butt-and-top grapple, approx. reach: 10.7 m | • self loading trucks |

| Year 2 | Small patch treatment | Patch treatment |
|---|---|---|
| Falling | • Timberjack 628 feller-buncher with 56-cm Koehring cutting head | • Koehring 628 feller-buncher with 56-cm cutting head |
| Skidding | • John Deere 748G rubber-tired skidder and grapple | • John Deere 748G rubber-tire skidder and grapple |
| Processing | • Hyundai Robex 200LC with Denis 3000 stroker<br>• Hyundai Robex 210LC with Denis 3500 stroker | • Hyundai Robex 210LC with Denis 3500 stroker |
| Loading | • Madill 2800 Log Loader with butt-and-top grapple | • Hyundai Robex 290LC Road Builder with a grapple-clam rake |

# Appendix II

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

| | John Deere 648G | John Deere 748G | Caterpillar D5H TSK track skidder | 25–30 t feller-buncher w/disk saw | 30–35 t feller-buncher w/disk saw | 15–20 t feller-processor w/Log Max 5000 head | Processor on 25–30 t carrier | 35–40 t log loader w/butt-n-top |
|---|---|---|---|---|---|---|---|---|
| OWNERSHIP COSTS | | | | | | | | |
| Total purchase price (P) $ | 255000 | 315000 | 410000 | 510000 | 550000 | 385000 | 460000 | 555000 |
| Expected life (Y) y | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 6 |
| Expected life (H) h | 12600 | 12600 | 12600 | 10800 | 10800 | 10800 | 15000 | 10800 |
| Scheduled hours/year (h)=(H/Y) h | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 2500 | 1800 |
| Salvage value as % of P (s) % | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Interest rate (Int) % | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Insurance rate (Ins) % | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Salvage value (S)=((P•s/100) $ | 63750 | 78750 | 102500 | 127500 | 137500 | 96250 | 115000 | 138750 |
| Average investment (AVI)=((P+S)/2) $ | 159375 | 196875 | 256250 | 318750 | 343750 | 240625 | 287500 | 346875 |
| Loss in resale value ((P-S)/H) $/h | 15.18 | 18.75 | 24.40 | 35.42 | 38.19 | 26.74 | 23.00 | 38.54 |
| Interest ((Int•AVI)/h) $/h | 7.08 | 8.75 | 11.39 | 14.17 | 15.28 | 10.69 | 9.20 | 15.42 |
| Insurance ((Ins•AVI)/h) $/h | 2.66 | 3.28 | 4.27 | 5.31 | 5.73 | 4.01 | 3.45 | 5.78 |
| Total ownership costs (OW) $/SMH | 24.92 | 30.78 | 40.06 | 54.90 | 59.20 | 41.44 | 35.65 | 59.74 |
| OPERATING COSTS | | | | | | | | |
| Fuel consumption (F) L/h | 25.0 | 25.0 | 25.0 | 30.0 | 30.0 | 30.0 | 25.0 | 30.0 |
| Fuel (fc) $/L | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| Lube & oil as % of fuel (fp) % | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Annual tire consumption (t) no. | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tire replacement (tc) $ | 2500 | 2500 | 0 | 0 | 0 | 0 | 0 | 0 |
| Track & undercarriage replacement (Tc) $ | 0 | 0 | 45000 | 30000 | 30000 | 25000 | 20000 | 38000 |
| Track & undercarriage life (Th) h | 0 | 0 | 6300 | 5400 | 5400 | 5400 | 10000 | 5400 |
| Annual operating supplies (Oc) $ | | | | | | | | |
| Annual repair & maintenance (Rp) $ | 30000 | 36000 | 46000 | 60000 | 65000 | 45000 | 50000 | 70000 |
| Shift length (sl) h | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 10.0 | 11.0 |
| Wages $/h | | | | | | | | |
| Operator | 23.38 | 23.38 | 23.38 | 25.37 | 25.37 | 25.79 | 24.49 | 24.49 |
| Total wages (W) $/h | 23.38 | 23.38 | 23.38 | 25.37 | 25.37 | 25.79 | 24.49 | 24.49 |
| Wage benefit loading (WBL) % | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| Fuel (F*fc) $/h | 13.75 | 13.75 | 13.75 | 16.50 | 16.50 | 16.50 | 13.75 | 16.50 |
| Lube & oil ((fp/100)•(F•fc)) $/h | 1.38 | 1.38 | 1.38 | 1.65 | 1.65 | 1.65 | 1.38 | 1.65 |
| Tires ((t•tc)/h) $/h | 2.78 | 2.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Track & undercarriage (Tc/Th) $/h | 0.00 | 0.00 | 7.14 | 5.56 | 5.56 | 4.63 | 2.00 | 7.04 |
| Repair & maintenance (Rp/h) $/h | 16.67 | 20.00 | 25.56 | 33.33 | 36.11 | 25.00 | 20.00 | 38.89 |
| Wages & benefits (W•(1+WBL/100)) $/h | 32.26 | 32.26 | 32.26 | 35.01 | 35.01 | 35.59 | 33.80 | 33.80 |
| Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h | 1.79 | 1.79 | 1.79 | 1.95 | 1.95 | 1.98 | 3.38 | 4.61 |
| Total operating costs (OP) $/SMH | 68.63 | 71.96 | 81.88 | 93.99 | 96.77 | 85.35 | 74.30 | 102.48 |
| TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH | 93.54 | 102.74 | 121.94 | 148.89 | 155.97 | 126.79 | 109.95 | 162.22 |

[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.