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Evaluation of a Timberjack 660D grapple skidder working on moderately steep slopes in coastal British Columbia

Abstract

The Forest Engineering Research Institute of Canada (FERIC) undertook a study with TimberWest Forest Corporation Ltd., to investigate the feasibility of using a rubber-tired grapple skidder to complement a loader-forwarding operation on moderately steep slopes in second-growth forests in coastal British Columbia. This report presents the productivity and cost of the skidding operation, identifies the factors that influence performance of the grapple skidder, and describes the soil disturbance resulting from skidding.

Keywords

Timberjack 660D grapple skidder, Harvesting, Skidding, Loader-forwarding, Productivity, Cost, British Columbia, Second growth, Steep slopes.

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Introduction

As forest companies in coastal B.C. move their harvesting into second growth stands on easy to moderately steep sites, the opportunity to use ground-based harvesting systems often arises. In the past, ground-based harvesting was found to be unacceptable due to excessive soil disturbance. However, over the past twenty years, the acceptance of constraints to forest operations has improved, understanding of equipment/soil relationships has increased, and equipment and techniques to reduce the machine ground pressure are more available. Feller-bunchers, processors, and skidders, if used appropriately, all offer the opportunity to reduce harvesting costs with acceptable site impacts. At the request of its members, FERIC has been investigating the use of this equipment in coastal second growth.

Forest companies in coastal B.C. use loader-forwarders extensively to extract timber on gentle to moderate slopes, in broken terrain, and on sensitive soils. Many loader-forwarding sites may also be suited for skidding with grapple skidders. Grapple skidders may be used either alone or in combination with loader-forwarders, particularly where extraction distances are long. In the fall of 2002, TimberWest Forest Corporation Ltd., Cowichan Woodlands Operation undertook a trial to investigate the feasibility of using a grapple skidder to complement a loader-forwarding operation. The trial took place on southern Vancouver Island on two blocks that were originally laid out exclusively for loader-forwarding. FERIC monitored the trial and the results are presented here. This report is the first of four that will be produced focussing on mechanized harvesting on the coast.

Objectives

The goals of this study were to assess the economic and operational feasibility of skidding with rubber-tired grapple skidders as an alternative to loader-forwarding, and to determine whether grapple skidding could meet applicable soil disturbance standards. The specific objectives were to:

- Determine overall productivity and cost for the skidding phase.
- Identify factors that influence performance of the grapple skidder.
- Evaluate the grapple skidder as a component of a typical coastal roadside harvesting operation.
- Document levels of soil disturbance on the site.
- Develop productivity and cost functions for the skidding operation.
- Examine the financial consequences of substituting a grapple skidder for a loader-forwarder.

Table 1. Site and stand descriptions

	Block A	Block B
Total area (ha)	5.92	13.13
Area skidded by grapple skidder (ha)	3.31	9.34
Area forwarded by loader-forwarder (ha)	2.61	2.31
Area previously logged (ha)	-	1.48
Site characteristics [a]		
Ecological classification [b]	CWHmm2	CWHmm2
Elevation range (m)	890-925	760-800
Terrain	gentle upper slope	undulating upper slope
Average slope (%)	10	18
Soils		
Soil depth (cm)	60	100
Mineral soil texture	S	SL-Sil
Coarse fragment content (%)	30	45
Compaction hazard	low	moderate
CPPA terrain classification [c]	1.2.2	downhill 1.4.2 uphill 1.2.2
Stand characteristics		
Species composition (%)		
Western hemlock	68	41
Douglas-fir	20	25
Western red cedar	3	16
Amabilis fir	8	14
Other	1	4
Maximum skidding distance (m)	250 adverse	100 favourable 150 adverse
Net merchantable volume (m^3)		
Per hectare	350	330
Per tree	0.4	0.5

[a] From Silviculture Plan.
[b] Green et al. 1994.
[c] Mellgren 1980.

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Site and stand description

The study site consisted of two blocks (A and B) approximately 30 km northwest of Duncan in the Vancouver Forest Region. Table 1 summarizes the site and stand features. The sites were classified as Coastal Western Hemlock moist montane subzone (CWHmm2) (Green et al. 1994). Topography was generally uneven to rough with slopes ranging from flat to 30%. Sand, sandy loam, and silt loam soils with high coarse fragment contents and very dry to moderately dry soil moisture regimes combined to create low soil compaction hazards.

Forest cover consisted of second-growth western hemlock *(Tsuga heterophylla),* western red cedar *(Thuja plicata),* Douglas-fir *(Pseudotsuga menziesii)*, and western white pine *(Pinus monticola)* in varying proportions. Merchantable stand and tree volumes ranged from 330 to 350 m³/ha and 0.4 to 0.5 m³/tree.

Harvesting operations

System description

Blocks A and B were initially identified for loader forwarding, but the harvesting prescriptions were amended to allow selected portions to be extracted with the grapple skidder. The use of the grapple skidder eliminated a planned 330-m spur road.

A fully mechanized roadside harvesting system was used and consisted of a Prentice 730A feller-buncher with a Gilbert side-tilting head, a new Timberjack 660D grapple skidder, a Hitachi EX270 loader-forwarder, and a Keto 500/Komatsu 2200C processor. The feller-buncher and processor operators were very experienced but had not worked previously as a team with a grapple skidder. The skidder operator was also experienced but had not operated a skidder of this power range before.

All machines were scheduled to work five days per week on a single-shift basis. The skidding and processing phases were scheduled to start about one week after felling started. To avoid production bottlenecks and provide a uniform flow of wood, the skidder was scheduled to work 8.5-h shifts while the feller-buncher and processor were each scheduled to work 10-h shifts.

Shortly before harvesting in study blocks was completed, the prescriptions were amended to harvest the leave trees originally prescribed. These were manually felled and loader-forwarded.

Skidder description

The Timberjack 660D grapple skidder is a four-wheel-drive rubber-tired skidder suitable to skid large loads of tree-length stems over long distances on steep or sensitive ground (Figure 1 and Table 2). The skidder is powered by a 135-kW diesel engine and is equipped with a 6-speed powershift transmission with a single-stage torque converter (standard on the 660D model). The

Figure 1. Timberjack 660D grapple skidder.

Table 2. Technical specifications of the Timberjack 660D grapple skidder

Engine	John Deere
Net power @ 2200 rpm (kW)	135
Length (m)	7.82
Width (m)	3.16
Wheelbase (m)	3.78
Ground clearance (m)	0.65
Operating weight (kg)	17 430
Transmission	single stage torque converter
Travel speed (km/h)	forward: 4.9–29.2 reverse: 4.9–21.4

torque converter matches pulling force to varying ground conditions, enabling the skidder to work smoothly on rough ground. The skidder has a long, wide wheelbase to maintain stability when skidding on slopes or broken terrain.

The skidder was equipped with 1.1-m-wide tires and chains on front and rear wheels (Figure 2). It was fitted with a hydraulically operated grapple with continuous 360-degree rotation, attached to a dual-function arch.[1] The grapple has a maximum opening of 3.3 m and an accumulating area of 1.48 m². The through-the-centre hose routing eliminates exposed hoses. The long reach of the arch (up to 2.95 m behind the rear-wheel axle), coupled with the grapple rotator, reduces the time required to position the skidder when accumulating its loads. The hydraulically tilted cab gives easy access to the transmission and other driveline components.

Figure 2. 1.1-m-wide tires and wheel chains.

Study methods

FERIC observed the harvesting operations and collected shift-level and detailed timing data on the skidding operation. Shift-level data for the skidding phase consisted of Servis recorder charts, operators' reports about daily production and major delays (>15 min/occurrence), and net harvest volumes from TimberWest scale records. Information for the loader-forwarding phase was obtained from the machine contractor.

Skidding cycles were detail-timed at frequent intervals throughout the study period. Each timed cycle was divided into five elements: Travel Unloaded, Load, Travel Loaded, Deck, and In-cycle Delays. Skidding distances, number of bunches per cycle, slope of the skidding route, and reasons for observed delays were also recorded. Using regression techniques, the timing data were analyzed to determine relationships between travelling times and skidding distances. The results of the regression analysis were then combined with average values for loading and decking times to develop equations to predict delay-free cycle time and to derive productivity and cost functions. Hourly skidder and loader-forwarder costs were calculated using FERIC's standard costing methods (Appendix I).

Soil disturbance surveys were performed using Forest Practices Code (FPC) survey methods and criteria on Blocks A, B, and C[2] (BCMOF 2001). During the skidding operation, soil samples were collected at randomly selected sites throughout the blocks to document soil moisture content at the time of skidding.

Skidding and loader-forwarding operations

The grapple skidder skidded 5 465 m³ and the loader-forwarder extracted 1 910 m³, for a total of 7 375 m³ from the two study blocks. Skidding in Block A and most of Block B was performed during an extended rainless period in October. The remainder of Block B was skidded in November, after a period of several days of rain. Loader-forwarding of both blocks was performed in November. Overall, the grapple skidder extracted 56% and 71% of the total areas of Blocks A and B, respectively (Figures 3 and 4).

On both blocks, the feller-buncher prepared bunches consisting of 6–12 stems. The bunches were aligned facing the presumed direction of skidding and the butts were evenly indexed.

The terrain on Block A was slightly even to uneven, with a moderate number of

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[1] The 660D model may be equipped with a cable winch or a dual arch grapple.

[2] The skidder demonstration was held on Block C and FERIC did not monitor the harvesting activities.

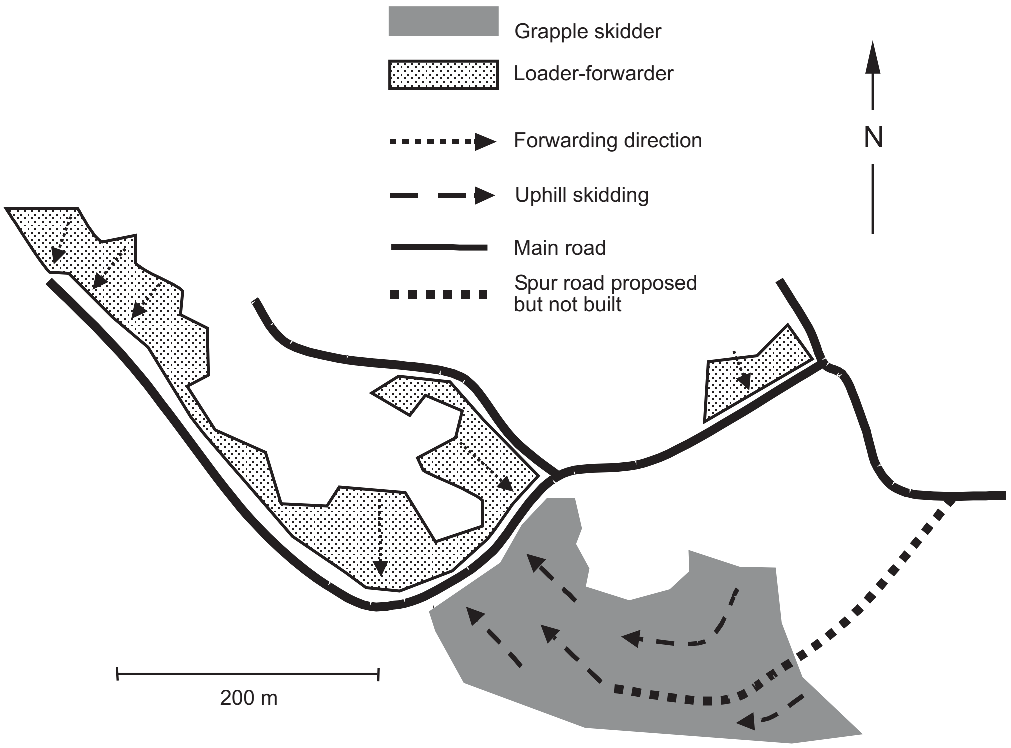

Figure 3. Layout and skidding pattern for Block A.

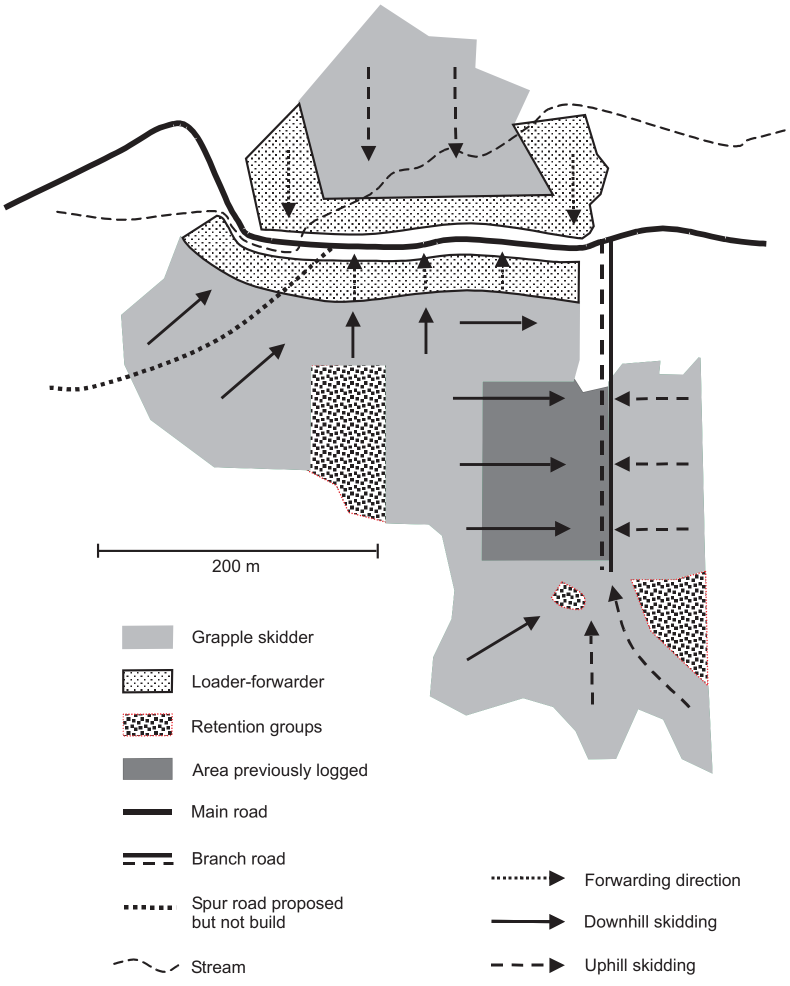

Figure 4. Layout and skidding pattern for Block B.

obstacles. Block A was skidded uphill on slopes 5–18% and averaging 10%. Skidding distances were up to 250 m (Figure 3). When skidding short distances (50 m or less), the operator preferred to travel in reverse from the decking area to the loading point using a dispersed skidding pattern. For longer distances, the operator travelled forward when unloaded and typically used the same skid trail several times, both unloaded and loaded.

Cycle payloads consisted almost exclusively of single bunches, and were visibly less than the skidder's capacity. If the stems in a bunch were properly indexed, the grapple arms maintained an excellent grip on the load regardless of bunch size. The grapple snubber dampened the movement of the skidded stems effectively even on very rough sections of skid trail. The stems were decked in a continuous row perpendicular to the road. Because the area available for decking was limited, the skidder used its blade and grapple to build high decks. This time-consuming task was required almost every second cycle. The processor usually had to stop working while the skidder pushed up the log decks.

Figure 5. Decking area prepared by a loader-forwarder.

Figure 6. Skidder releasing bunch on the top of the deck.

Both uphill and downhill skidding was done on Block B, where the grapple skidder handled about 80% of the total volume. The loader-forwarder extracted bunches from areas adjacent to the branch road and prepared decking areas along the spur road for uphill skidding and processing (Figure 5).

As in Block A, skidder payloads on Block B consisted almost exclusively of single bunches. The area of downhill skidding had the most difficult terrain observed in this study. The terrain was undulating and rough with numerous high stumps from previous logging activities and heavy accumulations of old slash in the decking and processing area. Slopes ranged from 10 to 25% and averaged 18% favourable. Skidding distances did not exceed 100 m so skidding traffic tended to be dispersed, but the operator often re-used the same trail several times when travelling loaded to avoid the many obstacles throughout the area. On several occasions the skidder became stuck on high stumps, and had to drop and then re-grapple its load. High stumps at roadside also hampered the skidder's ability to push up log decks with its blade, resulting in stem breakage. On other occasions, the skidder had to travel a considerable distance along the road until it could find a suitable gap in the deck to return to the skidding area.

The terrain in the uphill-skidded part of Block B was less difficult than in the downhill-skidded area, with slopes 0–15% and averaging 10% adverse. Bunches were well oriented, with easy access to their butts. The longest skidding distance was about 175 m. Dispersed skidding was used for short skidding, but the skidder operator tended to re-use skid trails on long skids and when skidding in the vicinity of leave patches. Decking with the skidder blade was required less frequently than in the downhill-skidded area. In several cases, the operator drove on the top of the deck before releasing the skidded bunch (Figure 6). Overall, the skidding operation on this area was visibly better than on the downhill-skidded area, due to the experience gained by the operator.

Results and discussion

Skidding phase - shift-level study

During the study the grapple skidder worked a combined total of 17 shifts on Blocks A and B, 7.0–10.5 h in length and averaging 8.4 h. Shift structure and productivities are summarized in Table 3. For the study period, the skidder's utilization was close to 100%, well above the long-term utilization level of 85% that is more typical for logging equipment (Kosicki 2000a).

Overall, skidding productivity and cost ranged from 33 m^3/scheduled machine hour (SMH) and \$3.80/m^3 (Block A, uphill skidding) to 39.8 m^3/SMH and \$3.15/m^3 (Block B, uphill skidding). Payloads on both blocks consisted almost exclusively of single bunches and averaged 3.13 m^3/cycle for Block A and 4.16 m^3/cycle for Block B, well below the values expected for a 135-kW skidder. The operator tried several times to build two-bunch loads but found it difficult due to the broken topography and his lack of experience on this machine. As a result he elected to skid single bunches even though the skidder was capable of skidding larger volumes.

Loader-forwarding distances were similar for both blocks, did not exceed 75 m, and averaged 20 m. The measured forwarding productivities of 27 and 34 m^3/SMH in Blocks A and B, respectively, were below the capabilities of the loader-forwarder, and resulted from irregular shapes of forwarded areas and extracting manually felled trees.[3] At an hourly cost of \$113.56/SMH, the forwarding costs were \$4.20/m^3 in Block A and \$3.34/m^3 in Block B.

Skidding phase - detailed-timing study

Results of the detailed-timing study are summarized in Tables 4 and 5. The longest elements of the skidding cycle were Travel Unloaded and Travel Loaded, which together accounted for 53 to 61% of the total cycle time (Table 5). The differences between Travel Unloaded and Travel Loaded times were not significant, indicating that the skidder's speed loaded was affected by the rough ground conditions rather than by the skidded loads.[4] The Deck element accounted for about 20% of the total cycle times and was much longer than the Load element.[5]

Table 3. Shift-level summary and productivity for the Timberjack 660D grapple skidder

Description	Block A	Block B
Productive shifts (no.)	4	13
Scheduled time (SMH)	31.3	111.3
Productive time (PMH)	31.3	108.0
Utilization (%)	100	97
Volume skidded (m^3)	1 032	4 433
Cycles (no.)	330	1 065
Volume/cycle (m^3)	3.13	4.16
Average skidding distance (m)	125	70
Productivity		
Volume/PMH (m^3)	33.0	41.0
Volume/SMH (m^3)	33.0	39.8
Machine cost (\$/SMH)	125	125
Skidding cost (\$/m^3)	3.80	3.15

Table 4. Detailed timing for the Timberjack 660D grapple skidder

Description	Block A	Block B
Productive time (min)	646	543
Productive machine hours (PMH)	10.8	9.1
Total cycles (no.)	102	132
Estimated volume (m^3) [a]	319	549
Average cycle time (min)	6.33	4.11
Average skidding distance (m)	140	70
Productivity (m^3/PMH)	30	61 [b]

[a] Using average volumes per cycle from shift-level study.

[b] This value is greater than that for the shift-level data (Table 3) because operating conditions were better during this part of the study.

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[3] George Fredrickson, Mount Sicker Lumber Company Ltd., Duncan, B.C., personal communication, February 2003.

[4] For ground-based skidding equipment, the travel speed unloaded is typically greater than the travel speed loaded (Henderson 2001; Kosicki 2000, 2002a, and 2002b).

[5] For grapple skidders, the deck time is typically much shorter than the load time (Henderson 2001; Kosicki 2000, 2002a, and 2002b).

Table 5. Summary of cycle times for the Timberjack 660D grapple skidder

	Block A		Block B			
Direction of skidding	uphill		downhill		uphill	
Average skidding distance (m)	140		63		76	
Average cycle time (min)	6.33		4.53		3.81	
Distribution of cycle time (min) ((%))						
Travel unloaded	1.89	(30)	1.28	(28)	1.08	(28)
Travel loaded	1.99	(31)	1.14	(25)	1.16	(30)
Load	0.75	(12)	0.71	(16)	0.34	(9)
Deck	1.33	(21)	0.94	(21)	0.71	(19)
Delays	0.37	(6)	0.46	(10)	0.52	(14)

The unusually long deck times were a result of the rough ground and limited area available for decking. Also, on numerous occasions the skidder had to travel long distances along the deck to find an opening to re-enter the skidding area. Loading and decking times decreased as the study progressed, as the skidder operator gained experience with the machine. In-cycle delay times were related almost exclusively to training of the operator and interactions with the processor.

Cycle time, productivity, and cost of skidding

Regression analysis based on the detail-timing data found a significant relationship between travelling times and skidding distances (Equations 1 to 6, Appendix II). These equations, combined with average loading and decking times from Table 5, were used to derive delay-free cycle times for the study areas (Equations 7 to 9, Appendix II).

Figure 7 presents predicted delay-free cycle time as a function of skidding distance for Blocks A and B. The differences in cycle times resulted mainly from differences in

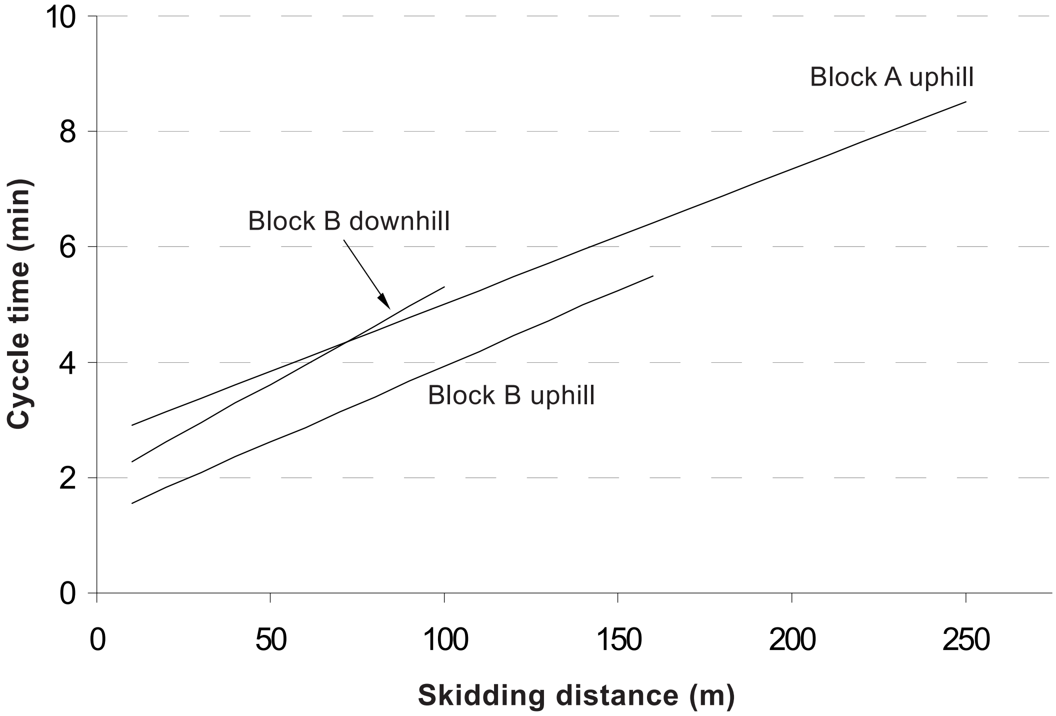

Figure 7. Delay-free cycle times for Blocks A and B as a function of skidding distance.

terminal times. The parallel regression lines indicate that the travel speeds of the skidder were similar on both blocks.[6] The steeper slope of the regression line for downhill skidding on Block B, compared to uphill skidding, indicates that travel speeds were slower than for uphill skidding. This is attributed to the rough terrain in this portion of Block B.

The shift-level and detailed-timing results were combined to estimate productivity during scheduled skidding time, using assumed long-term utilization of 85% (Equation 10, Appendix II). As Figure 8 shows, at a given distance there were substantial differences in skidding productivity between the two blocks, and between uphill and downhill skidding. The highest productivity was achieved in the uphill skidded portion of Block B—about 30% greater than for downhill skidding on the same block, and about 40–50% greater than for uphill skidding on Block A. The productivity differences are attributed to differences in both cycle times and payloads. Generally, however, productivities in all situations were below those expected for a 135-kW skidder. Reasons for this are discussed in the later section "Comparison with other studies."

Skidding costs (estimated using Equation 11, Appendix II) ranged from $2.63/m³ to $4.23/m³ for a skidding distance of 100 m (Figure 9). By comparison, loader-forwarding costs for a 20-m extraction distance were $4.20/m³ for Block A and $3.34/m³ for Block B (Figure 10). The high forwarding costs in this study were due to low forwarding productivity of manually felled trees.[7] If the site had been harvested with only the loader-forwarder system (as originally planned), the estimated productivity would have been 24 m³/SMH[8] at an average extraction distance of 70 m, and the cost would have been $4.73/m³. This cost estimate agrees very closely with costs established in a previous loader-forwarding study.[9]

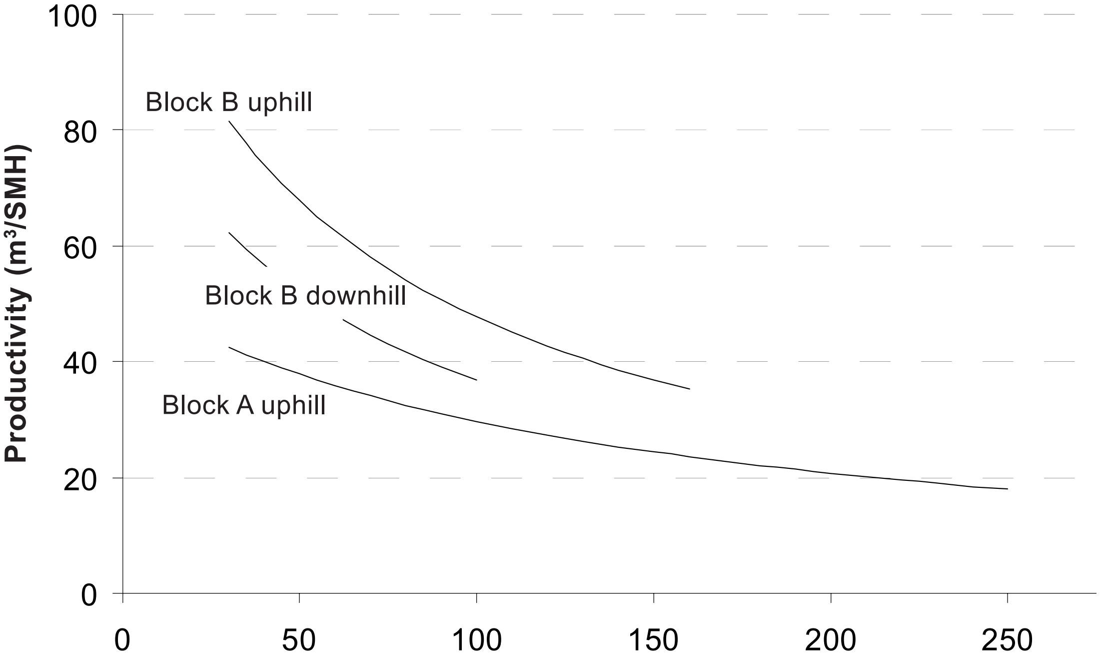

Figure 8. Skidding productivities for Blocks A and B as functions of skidding distance.

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[6] The differences between regression coefficients in equations for combined travel times unloaded and loaded are not significant at $\propto = 0.05$.

[7] During the first few passes, the manually felled dispersed stems required additional handling to create multi-stem loads. For these passes also, the forwarding distances were usually short. Small loads and short distances combined resulted in low forwarding productivity.

[8] George Fredrickson, Mount Sicker Lumber Company Ltd., Duncan, B.C., personal communication, February 2003.

[9] Kosicki, K.; Dyson, P. Report in preparation. Mechanized second growth harvesting on steep slopes. FERIC, Vancouver, B.C.

Figure 9. Skidding cost for Blocks A and B as a function of skidding distance.

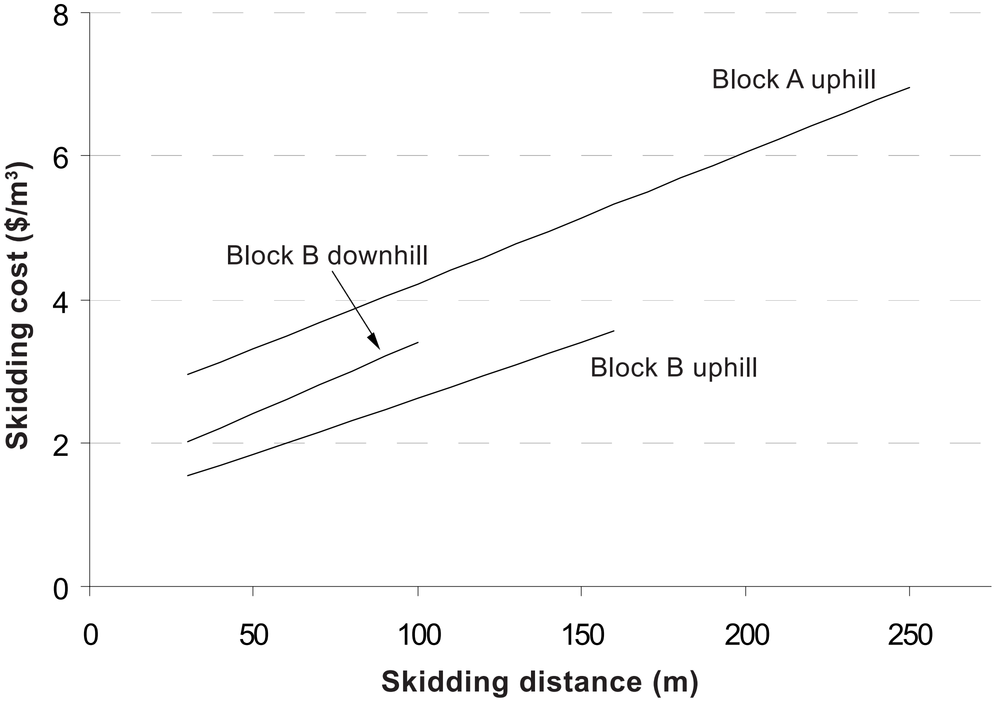
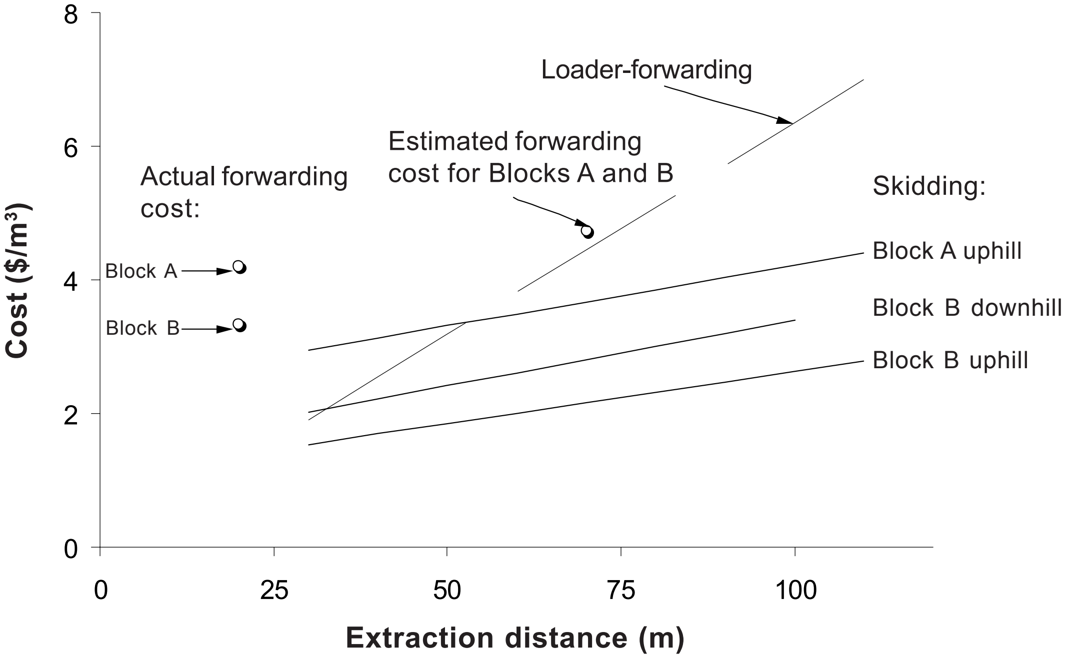


Figure 10. Skidding and loader-forwarding costs as functions of extraction distance.



If the loader-forwarder had prepared the decking area by removing large debris accumulated during earlier harvesting operation and extracted stems from the band adjacent to the road, skidding productivity may have increased with a corresponding reduction in skidding costs. For example, in the skidded portion of Block A, these measures could have reduced the skidder's decking time from 1.33 to 0.60 min/cycle (Kosicki 2002a). For an hourly skidder cost of $125.52/SMH and an average payload of 3.13 m³/cycle, the skidding costs would have been reduced by $0.49/m³.

Comparison with other studies

In this study, predicted cycle times for a 100-m skid distance varied from 4.0 to 5.3 min depending on skidding direction (uphill or downhill) and terrain. In comparison, Kosicki (2000a) reported cycle times of about 3.1 min for 120-kW skidders at the same distance but under more favourable skidding conditions (level terrain, no ground obstacles, ample decking area, one bunch per cycle, and experienced operators). For a skidding distance of 150 m, the lowest cost of \$3.40/m³ achieved in this study for uphill skidding in Block B was 60 to 90% higher than that of the 120-kW grapple skidders (Kosicki 2000 and 2000a). Since the estimated hourly costs for the 120-kW skidders were 10 to 15% less than the estimated hourly cost for the Timberjack 660D, the differences in cost per cubic metre were due almost exclusively to differences in skidding productivities.

When compared with a recent study of loader-forwarding,[10] the results of this study suggest that skidding with a grapple skidder is more productive and cost-effective than loader-forwarding when extraction distances exceed about 50 m (Figure 10).

Skidding and loader-forwarding compared to loader-forwarding only

Total harvesting costs for the two blocks were compared for the loader-forwarder-and-grapple-skidder option (as observed in this trial) and the loader-forwarding-only option (as originally planned). The analysis assumed that feller-bunching and processing costs were not affected by the choice of skidding system. The productivities and costs of the loader forwarder-and-grapple-skidding system were based on the actual results of the shift-level study. The loader-forwarder contractor supplied information on road construction costs and estimated loader-forwarder productivities and hourly costs for the loader-forwarding-only option.

The results of the analysis are summarized in Table 6. Compared to the loader-forwarding-only option, using the grapple skidder eliminated a 330-m spur road and reduced the total machine hours required to harvest the two blocks. Skidding/forwarding costs were reduced from \$35 658 for loader-forwarding only to \$25 217 for combined loader-forwarding/grapple-skidding, and road construction costs were reduced by \$9 900, for a total savings of \$20 341 or \$2.76/m³.

Table 6. Summary of extraction costs for loader-forwarding-only and loader-forwarding-and-grapple skidding systems

Description	Loader-forwarder-only system	Loader forwarder-and-skidder system
Volume forwarded (m³)	7 375	1 910
Volume skidded (m³)	n.a. [a]	5 465
Forwarding productivity (m³/SMH)	23.5	30.0
Skidding productivity(m³/SMH)	n.a.	38.3
Forwarding time (SMH)	314	64
Skidding time (SMH)	n.a.	143
Total extraction time (SMH)	314	207
Forwarder cost (\$/SMH)	113.56	113.56
Skidder cost (\$/SMH)	n.a.	125.52
Forwarding cost (\$)	35 658	7 268
Skidding cost (\$)	n.a.	17 949
Road construction cost (\$)	9 900	n.a.
Total cost (\$)	45 558	25 217
Cost (\$/m³)	6.18	3.42

[a] n.a. - not applicable.

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[10] Kosicki, K.; Dyson, P. Report in preparation. Mechanized second growth harvesting on steep slopes. FERIC, Vancouver, B.C.

Expected skidding productivity and cost

The grapple skidder's productivity in this study was less than would be expected for a 135-kW skidder. Therefore, results (travelling time, terminal times, delays, and payload) were compared against earlier FERIC studies on grapple skidders of similar size and power range (Kosicki 2000 and 2000a; Gingras and Godin 2001) to estimate its potential productivity. Table 7 and Figure 11 suggest that for uphill skidding at a distance of 100 m, the expected productivity should be about 71 m³/SMH, or 48% higher than the estimated productivity of 48 m³/SMH based on the average turn volume observed in this study. Skidding costs would be reduced by about 33%, from $2.62 to $1.76 per m³ (Figure 12).

Table 7. Estimated productivity and cost of the Timberjack 660D grapple skidder using observed and expected cycle times and turn volumes

Description	Observed values [a]	Expected values
Travel time [b] (min)	2.86	2.86
Bunches to complete a full load (no./cycle)	1	2
Loading time (min/cycle)	0.34	0.75
Decking time (min/cycle)	0.71	0.60
Delays (min/cycle)	0.52	0.15
Cycle time (min)	4.43	4.36
Payload (m^3/cycle)	4.16	6.1 [c]
Productivity (m^3/PMH)	56.3	83.9
Utilization (%)	85	85
Productivity (m^3/SMH)	47.9	71.4
Cost ($/SMH)	125.52	125.52
Cost ($/$m^3$)	2.62	1.76

[a] Based on study results in Block B, uphill skidding.
[b] By Equations 3 and 6 in Appendix II and skidding distances of 100 m.
[c] For payload estimate see Appendix III.

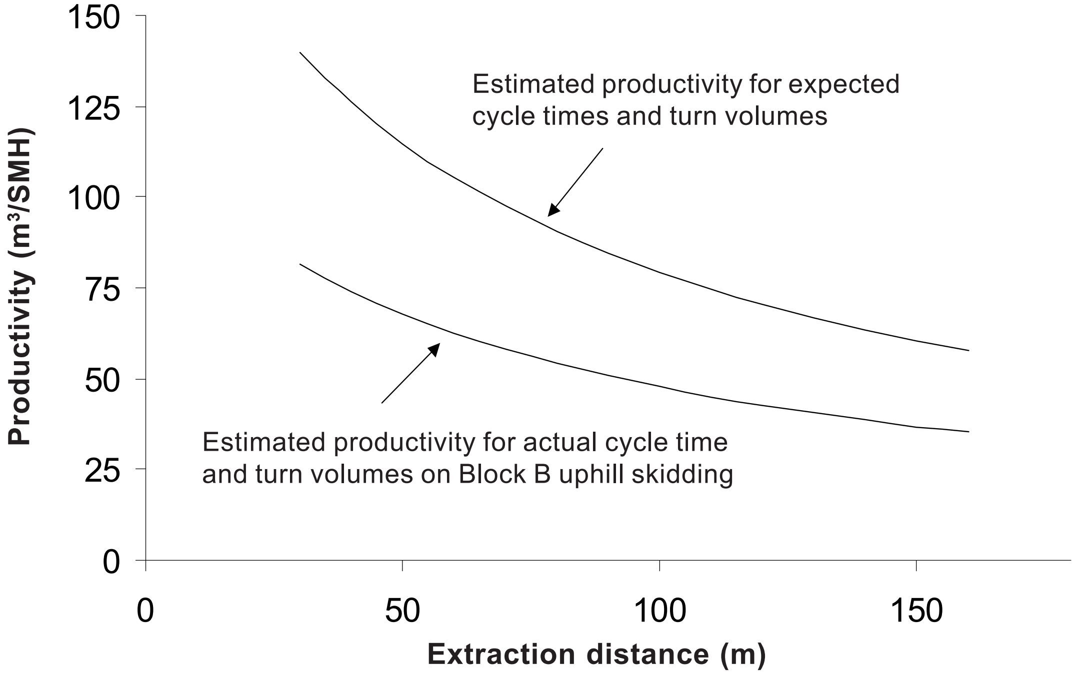

Figure 11. Estimated skidding productivities for the Timberjack 660D grapple skidder based on actual and expected cycle times and turn volumes.

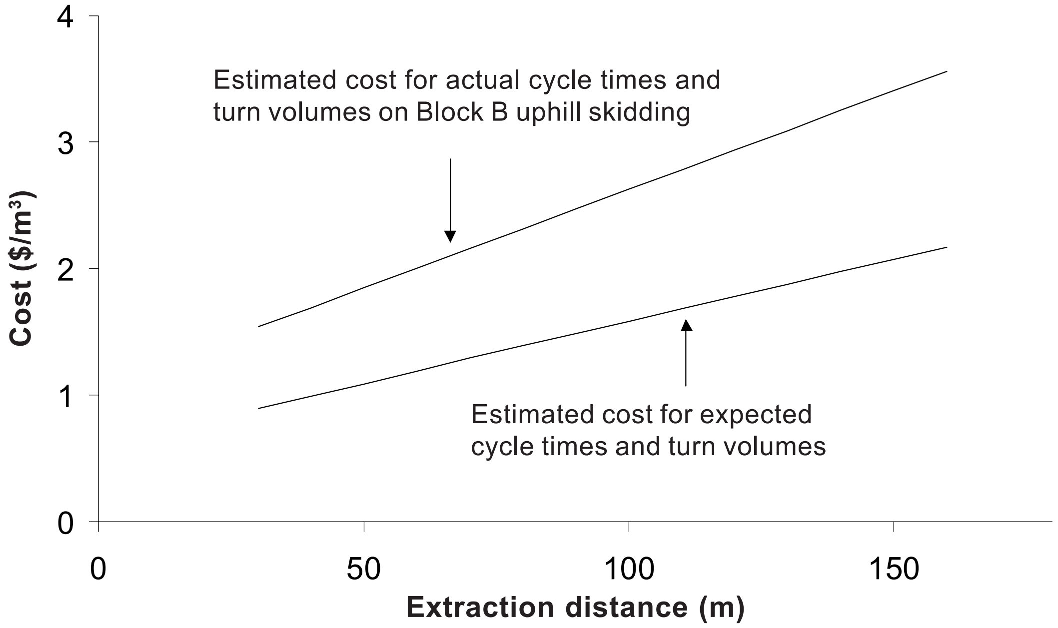

Figure 12. Estimated skidding costs for the Timberjack 660D grapple skidder based on actual and expected cycle times and turn volumes.

Table 8. Summary of soil disturbance and soil displacement

	Block A	Block B	Block C
Soil disturbance (%) (SE[a])	1.0	2.8 (0.8)	0.4
Forest floor displacement (%) (SE)	1.0	5.8 (1.1)	1.2
Exposed mineral soil (%)	0.21	0.06	0.00

[a] Standard error.

Soil disturbance

Soil disturbance was lower in Block A, at 1.0%, than in Block B, at 2.8% (Table 8). Forest floor displacement was also lower in Block A than in Block B (1.0% compared to 5.8%). The disturbance in both blocks was less than the maximum allowable level of 5% specified by the FPC for the B.C. coast. The very dry to moderately dry soil moisture levels at the time of the study,[11] low to moderate soil compaction hazard for the sites and use of wide tires contributed to these favourable results. To further reduce soil disturbance, skidding should stop during rain events when rutting is evident. A loader-forwarder can usually be used under these wetter conditions. Loader-forwarders should also be used in sensitive areas of the block, for example, near streams.

An additional block, Block C, with an average slope of 2.0%, was also surveyed and the soil disturbance was low at 0.4%.

Exposed mineral soil encourages the establishment of alder that in turn competes with conifer regeneration. To determine if alder competition would be a problem, the amount of exposed mineral soil was measured and found to be very low at 0.21% for Block A and 0.06% for Block B.

Conclusions

The study demonstrated that skidding of moderately steep clearcuts in second-growth stands using a grapple skidder is a feasible alternative to traditional loader-forwarding under some conditions.

The Timberjack 660D grapple skidder was able to travel smoothly over steep and rough terrain while causing low ground disturbance. The long reach of its arch and the grapple rotator enabled the Timberjack 660D to pick up bunches efficiently even when their orientation differed sharply from the direction of skidding. The grapple arms maintained excellent grip on properly indexed bunches of all sizes, and logs slipped out of the grapple only occasionally. The grapple snubber dampened the movement of the

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[11] Block A was skidded before it rained and the soil moisture content was 15%. Block B was skidded after the rainfall and the soil moisture content was 23%.

skidded stems effectively even on the very rough sections of the terrain.

Skidding productivity in the two study blocks did not reflect the true potential of the 135-kW grapple skidder. Factors adversely affecting skidding productivity included small volumes per stem and per hectare, difficult skidding and decking conditions (high stumps, accumulations of large debris, and rough and confined decking area), and the skidder operator's lack of experience with this particular machine. However, productivity of future skidding operations can be improved easily by better planning and supervision, and more experience.

This study suggests that a grapple skidder and loader-forwarder, as a team, can complement each other very well. The grapple-skidder's large payload volume and high travelling speed make it very efficient for long-distance extraction in a favourable (downhill) direction on moderate to steep, smooth slopes with few obstacles. Because of its low speed, the loader-forwarder is better suited for short extraction distances. It may be best employed to forward stems from bands adjacent to the roads and areas inaccessible to a grapple skidder (small confined pockets, steep slopes, extraction in an adverse direction, and sensitive soils).

Since the essential requirements of felling patterns, bunch sizes, and directions of extraction for skidding and loader-forwarding are the same, both extraction methods are interchangeable after felling and may complement each other. This can be an advantage when the weather (e.g., rain) or ground conditions (steep or sensitive areas in a block) prohibit skidding because of soil conservation concerns. Complementing loader-forwarding with skidding may also result in a reduction of roads required in a block because the skidder's productivity and cost are less sensitive to extraction distance than the loader-forwarder.

The financial analysis showed that the introduction of the Timberjack grapple skidder to the study block resulted in a considerable time saving and reduced skidding/forwarding costs by \$2.76 /m^3, or 45%, compared to loader-forwarding-only.

At a distance of 100 m, the potential skidding productivity and cost with the Timberjack 660D were estimated at 71 m^3/SMH and \$1.76/m^3, respectively.

All blocks were within the maximum allowable disturbance levels specified by the FPC for the coast of 5%.

Implementation

The study highlighted several factors that can contribute to the successful employment of grapple skidders in coastal second growth in roadside harvesting operations.

- Effective skidding with grapple skidders to realize cost reduction benefits requires careful layout of the block and detailed planning of all harvesting phases.
- Fewer roads may be needed in a skidded block compared to a loader-forwarded block. Skidding distances can be longer than loader-forwarding distances, but they should not exceed 250 to 300 m. On moderately steep slopes, the direction of skidding may be not the crucial factor, but downhill skidding is generally recommended.
- If a "hot logging" system[12] is used, the system can be balanced by adjusting the number of machines, number of shifts per day, or scheduled shift lengths. A balanced operation will reduce delays related to interactions between the harvesting phases and will minimize the total harvesting time.
- In more difficult terrain, an early field reconnaissance of the block for contractors, equipment operators, and supervisors will give the opportunity for all involved to analyze working conditions, strategize, and establish cooperation.
- The feller-buncher operator should be familiar with the block layout, general direction of skidding, and capabilities of the skidder to correctly place and index bunches of appropriate sizes.
- If the bunch sizes are below skidder capacity, the skidder operator should optimize the payload size by collecting multiple bunches. This will maximize productivity, especially in the case of long skidding distances.
- If the loader-forwarder removes large debris from the decking areas and extract stems from the bands adjacent to the road, the skidder's productivity will increase. Skidder traffic adjacent to the road, and subsequent soil disturbance in the decking area will decrease.
- Try to balance skidding and processing and prepare small production buffers between these operations.
- Reduce disturbance to roadside areas by using processors and loaders that can perform their tasks while working on the haul road surface.
- In the case of adverse weather conditions and signs of rutting, stop skidding until conditions improve.

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[12] In a "hot logging" system two or more harvesting phases (e.g., skidding, processing, and loading) occur simultaneously. The supply buffer between phases is generally small.

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Appendix I

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

	Timberjack 660D grapple skidder	Hitachi EX270 loader-forwarder
OWNERSHIP COSTS		
Total purchase price (P) $	375 000	335 000
Expected life (Y) y	6	10
Expected life (H) h	12 000	14 400
Scheduled hours/year (h)=(H/Y) h	2 000	1 440
Salvage value as % of P (s) %	25	20
Interest rate (Int) %	7.1	7.1
Insurance rate (Ins) %	3.0	3.0
Salvage value (S)=((P•s)/100) $	93 750	67 000
Average investment (AVI)=((P+S)/2) $	234 375	201 000
Loss in resale value ((P-S)/H) $/h	23.44	18.61
Interest ((Int•AVI)/h) $/h	8.32	9.91
Insurance ((Ins•AVI)/h) $/h	3.52	4.19
Total ownership costs (OW) $/h	35.27	32.71
OPERATING COSTS		
Fuel consumption (F) L/h	25.0	25.0
Fuel (fc) $/L	0.70	0.70
Lube & oil as % of fuel (fp) %	15	15
Annual tire consumption (t) no.	1.2	-
Tire replacement (tc) $	6 000	-
Track & undercarriage replacement (Tc) $	-	16 000
Track & undercarriage life (Th) h	-	8 000
Annual repair & maintenance (Rp) $	50 000	26 500
Shift length (sl) h	8.5	8.0
Wages $/h	28.8	28.8
Wage benefit loading (WBL) %	40	40
Fuel (F•fc) $/h	17.50	17.50
Lube & oil ((fp/100)•(F•fc)) $/h	2.63	2.63
Tires ((t•tc)/h) $/h	3.60	-
Track & undercarriage (Tc/Th) $/h	-	2.00
Repair & maintenance (Rp/h) $/h	25.00	18.40
Wages & benefits (W•(1+WBL/100)) $/h	40.32	40.32
Overtime (0.5W(sl-8)(1+WBL/100)/sl) $/h	1.19	-
Total operating costs (OP) $/SMH	90.24	80.85
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH	125.51	113.56

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

Appendix II

Regression, productivity, and cost equations

Linear equations for travelling unloaded and loaded

Equation 1: Travel unloaded, Block A, uphill skidding

$TE = 0.25 + 0.0117(SD)$ $n = 102$ cycles $r^2 = 0.84$ $S.E.E. = 0.348$

Equation 2: Travel unloaded, Block B, downhill skidding

$TE = 0.16 + 0.0177(SD)$ $n = 57$ cycles $r^2 = 0.57$ $S.E.E. = 0.372$

Equation 3: Travel unloaded, Block B, uphill skidding

$TE = 0.21 + 0.0114(SD)$ $n = 75$ cycles $r^2 = 0.67$ $S.E.E. = 0.317$

Equation 4: Travel loaded, Block A, uphill skidding

$TL = 0.35 + 0.0116(SD)$ $n = 102$ cycles $r^2 = 0.87$ $S.E.E. = 0.292$

Equation 5: Travel loaded, Block B, downhill skidding

$TL = 0.13 + 0.0159(SD)$ $n = 57$ cycles $r^2 = 0.73$ $S.E.E. = 0.234$

Equation 6: Travel loaded, Block B, uphill skidding

$TL = 0.03 + 0.0149(SD)$ $n = 75$ cycles $r^2 = 0.87$ $S.E.E. = 0.234$

where

TE = travelling time unloaded (min)
SD = skidding distance (m)
n = number of observation
r^2 = coefficient of determination
S.E.E. = standard error of estimate

Cycle time equations

Equation 7: Block A, uphill skidding $CT = 2.68 + 0.0233(SD)$
Equation 8: Block B, downhill skidding $CT = 1.94 + 0.0336(SD)$
Equation 9: Block B, uphill skidding $CT = 1.29 + 0.0263(SD)$

where:

CT = delay-free cycle time (min)
SD = skidding distance (m)

Productivity and cost equations

Equation 10: $\text{Productivity} = \dfrac{60(CV)(U)}{CT + DT}$

Productivity = predicted productivity measured in m^3/SMH
CV = average volume per skidding cycle (m^3)
U = utilization (%/100)
CT = cycle time from appropriate cycle time equation (min)
DT = “in-cycle” delay time per cycle (min)

Equation 11: $\text{Cost} = \dfrac{HC}{\text{Productivity}}$

where:

Cost = predicted skidding cost in $/$m^3$
HC = estimated skidding cost in $/SMH
Productivity = predicted skidding productivity in m^3/SMH from Equation 10

Appendix III

Estimate of the expected payload for the Timberjack 660D

The following estimate of the expected payload for the Timberjack 660D grapple skidder in future harvest operations is based on earlier FERIC studies on four grapple skidders of similar sizes and power ranges (Kosicki 2000 and 2000a, Gingras and Godin 2001). For these skidders, the following indices were calculated:

- Payload in m³ per 1000 kg of the skidder weight
- Payload in m³ per kW of the engine power
- Payload in m³ per 1 m² of the grapple cross-sectional area

Table A. Indices for selected models of grapple skidders

Description	John Deere 748E	Timberjack 560	John Deere 748E	Tigercat 630	Average
Skidder weight (kg)	14 560	15 400	14 560	14 750	14 818
Engine power (kW)	123	118	123	137	125
Grapple area (m²)	1.07	0.92	1.07	1.30	1.09
Load (m³)	5.40	5.30	5.30	6.75	5.69
Load in m³ per:					
1000 kg of skidder weight	0.37	0.34	0.36	0.46	0.38
1 kW of engine power	0.044	0.045	0.043	0.049	0.045
1 m² of grapple area	5.0	5.8	5.0	5.2	5.2

Then, the average index values were used to calculate the expected loads in m³ for the Timberjack 660D grapple skidder (Table B).

Table B. Expected payload calculations for the Timberjack 660D grapple skidder

Description	Total
Skidder weight (kg)	17 430
Engine power (kW)	135
Grapple area (m²)	1.48
Load in m³/1000 kg of skidder weight	0.38
Load in m³/kw of engine power	0.045
Load in m³/m² of grapple area	5.2
Expected load in m³ by	
Skidder weight	6.6
Engine power	6.1
Grapple area	7.7

For calculations of expected productivity and cost with the Timberjack 660D, a payload of 6.1 m³ resulting from the engine power was selected.