Advantage

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Contents

Loader-forwarding on moderately steep slopes in interior British Columbia

Abstract

In 1999, the Forest Engineering Research Institute of Canada (FERIC) performed a study on a loader-forwarding operation in interior British Columbia. The study provided information about the harvesting operation's productivity and costs. Loader-forwarding trails were surveyed and the proportion of cutblock area occupied by trails and mapped extraction routes are presented.

Keywords

Harvesting systems, Loader-forwarding, Soil disturbance, Productivity, Costs, Interior British Columbia.

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Introduction

To provide information on costs and productivities for alternative harvesting techniques aimed at minimizing soil disturbance, FERIC has an ongoing program to study ground-based harvesting on steep and/or sensitive sites. Two case studies that have been completed include a Trans-Gesco clambunk skidder working with a loader-forwarder on moderately steep slopes (Kosicki 2001), and low ground-pressure skidders working in northwestern B.C. (Henderson 2001). In the summer of 1999, FERIC and Ainsworth Lumber Co. Ltd. studied a loader-forwarding operation on moderately steep ground as an alternative to cable extraction on three cutblocks in the interior of British Columbia. Both hand falling with loader-forwarding and hand falling with cable yarding were used during harvesting. For the purpose of this report, only the loader-forwarding operations were studied.

Objectives

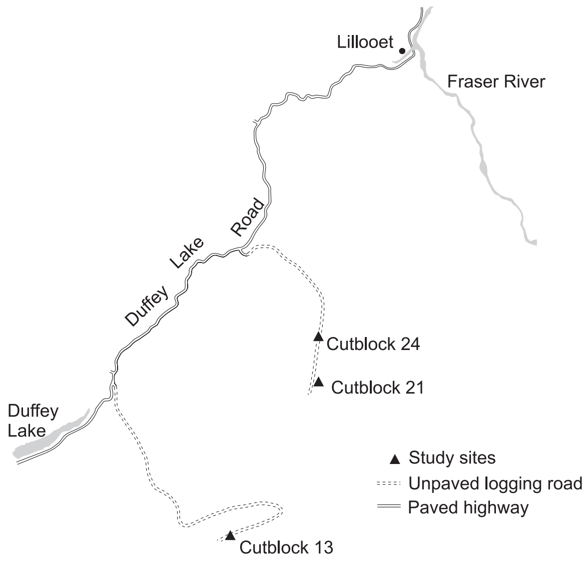
The primary goal of this study was to assess the economic and operational feasibility of using hydraulic log loaders to forward timber in moderately steep clearcut blocks. The following specific objectives were set:

- Determine overall productivities and costs for the loader-forwarding operation.
- Determine the proportion of cutblock area occupied by loader-forwarding trails.
- Identify operational factors affecting performance of the harvesting phase and recommend improvements where appropriate.

Site description

The study sites were located approximately 40 km southwest of Lillooet in Ainsworth's Timber Supply Area within the Kamloops Forest Region (Figure 1). The sites were classified as dry very cold (dv) and moist warm (mw) subzones within the Engelmann Spruce-Subalpine Fir (ESSF) biogeoclimatic zone (Lloyd et al. 1990). Table 1 summarizes site and stand attributes for the three cutblocks.

Figure 1. Location of study sites.



Silviculture prescription

The silvicultural system for all three cutblocks was clearcut with the preferred harvest method stated as cable yarding, and with hoe chucking (loader-forwarding) as an alternative. Cutblock 21 was harvested entirely by loader-forwarding, whereas Cutblocks 24 and 13 utilized both cable yarding and loader-forwarding timber extraction methods.

Cutblock 21 had low to moderate ratings for site sensitivity to soil degrading processes, and had a maximum soil disturbance level of 10% as stated within the silviculture

Table 1. Site and stand attributes

<table>
<tr><th rowspan="2"></th><th colspan="2">Boulder Creek</th><th>Blowdown Creek</th></tr>
<tr><th>Cutblock 21</th><th>Cutblock 24</th><th>Cutblock 13</th></tr>
<tr><td>Elevation range (m) [a]</td><td>1600–1680</td><td>1500–1585</td><td>1160–1285</td></tr>
<tr><td>Slope (%) [b]</td><td></td><td></td><td></td></tr>
<tr><td>Range</td><td>15–39</td><td>15–41</td><td>10–39</td></tr>
<tr><td>Average</td><td>30</td><td>35</td><td>35</td></tr>
<tr><td>Area harvested by loader-forwarding (ha)</td><td>3.8</td><td>3.3</td><td>9.6</td></tr>
<tr><td>Maximum forwarding distance (m)</td><td>205</td><td>195</td><td>155 favourable
160 adverse</td></tr>
<tr><td>Species composition (%) [c]</td><td colspan="2"></td><td></td></tr>
<tr><td>Engelmann/white spruce</td><td colspan="2">84</td><td>52</td></tr>
<tr><td>Amabilis fir</td><td colspan="2">12</td><td>29</td></tr>
<tr><td>Lodgepole pine</td><td colspan="2">3</td><td>-</td></tr>
<tr><td>White pine</td><td colspan="2">-</td><td>6</td></tr>
<tr><td>Douglas-fir</td><td colspan="2">1</td><td>1</td></tr>
<tr><td>Western red cedar</td><td colspan="2">-</td><td>2</td></tr>
<tr><td>Western hemlock</td><td colspan="2">-</td><td>10</td></tr>
<tr><td>Stand parameters [c]</td><td colspan="2"></td><td></td></tr>
<tr><td>Net merchantable volume (m³/ha)</td><td colspan="2">662</td><td>672</td></tr>
<tr><td>Stand density (stems/ha)</td><td colspan="2">946</td><td>628</td></tr>
<tr><td>Average net volume (m³/tree)</td><td colspan="2">0.70</td><td>1.07</td></tr>
<tr><td>Average dbh of live trees (cm)</td><td colspan="2">32</td><td>38</td></tr>
<tr><td>Average tree height (m)</td><td colspan="2">28</td><td>36</td></tr>
</table>

a For entire cutblocks.
b For loader-forwarding portion of cutblocks only, cable yarding portions are slightly steeper.
c Taken from operational cruise summary.

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prescription. Cutblocks 24 and 13 had high to very high ratings, and each had a maximum soil disturbance level of 5%.

Streams within the cutblocks were classified as S5 and S6[1] and had riparian management zones of 30 and 20 m, respectively. The two drainages had numerous avalanche chutes used by foraging mammals including grizzly bear. Wildlife tree patches 1.9 to 3.2 ha in size were established adjacent to or near the avalanche chutes to provide shelter and habitat.

Harvesting system and equipment

Pietila and Sons Logging Ltd. of Lillooet, B.C. harvested the loader-forwarding portion of all three cutblocks. This harvest method was new to the crew. The cutblocks were manually clear-felled and only the high-value peeler logs were bucked to length and delimbed at the stump. The forwarding was done primarily by two Kobelco SK 300-LC hydraulic log loaders working independent of each other. Occasionally, either machine would be used to load the trucks.

Truck loading was done primarily by a Kobelco SK 220-LC hydraulic log loader, but this machine also forwarded stems to roadside occasionally. A landing bucker bucked and delimbed the stems as they were spread out at the decking areas (Figure 2). When time permitted, the bucker delimbed stems within the cutblock and/or reduced the height of stumps along the loader-forwarding travel path.

The Kobelco SK 300-LC has an operating weight of approximately 33 tonnes. The width of the machine is 3.6 m, with each track measuring 80 cm wide. The standard configuration has a static ground pressure of 0.48 kg/cm^2. The clearance below the machine is approximately 80 cm. The grapples on the two machines are slightly different in size; one opens to a width of 1.32 m, and the other to a width of 1.64 m. Both machines have a reach of approximately 10 m.

Figure 2. Final forwarding pass to roadside.

The Kobelco SK 220-LC is slightly smaller, with an operating weight of approximately 25 tonnes and width of 3.5 m. The track width is 80 cm wide, and static ground pressure is 0.39 kg/cm^2 for the standard configuration. The clearance below the machine is approximately 72 cm. The grapple has an opening of 1.45 m, and the reach of the machine is approximately 9.5 m.

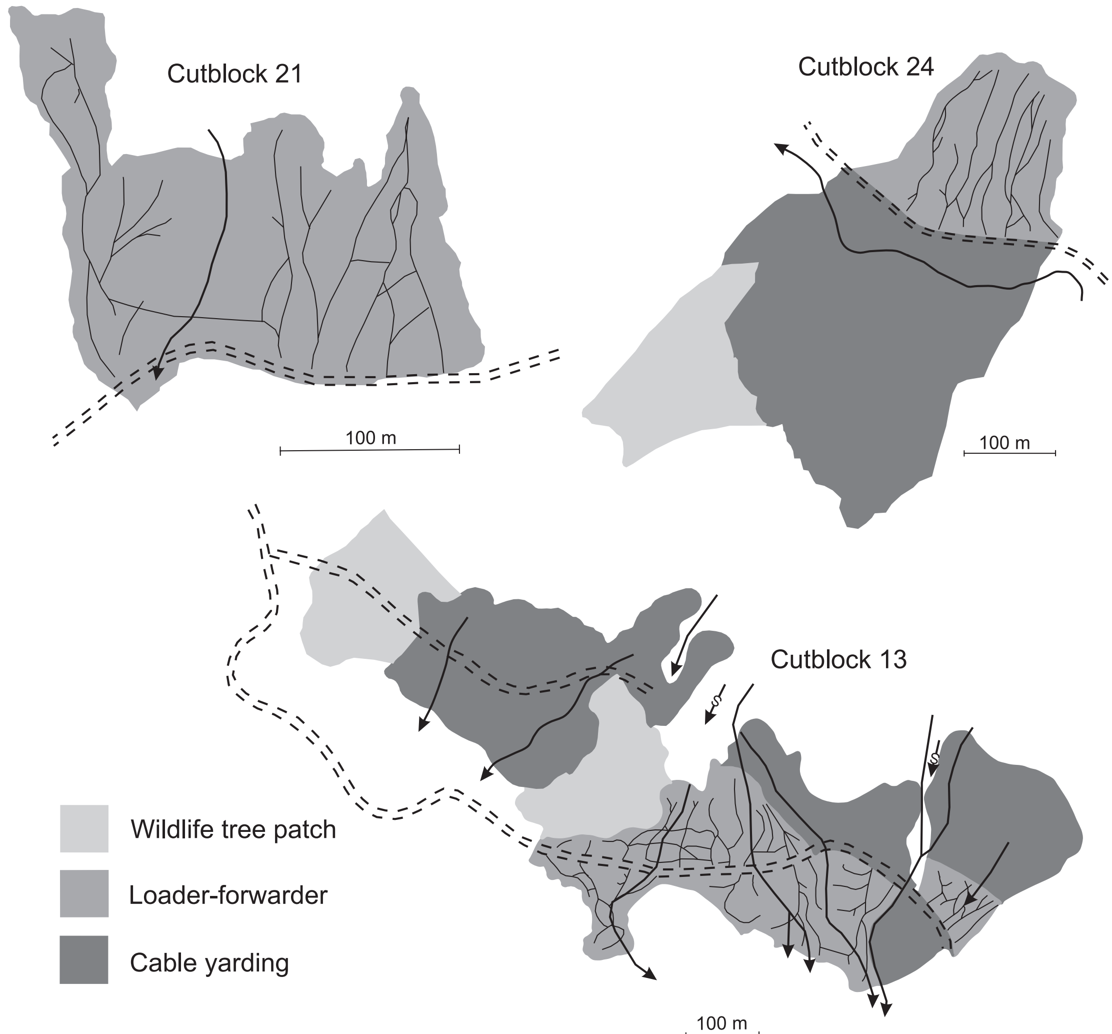
The cutblocks and roads were laid out for cable yarding. Although sections of the road had steep cutbanks and fill slopes, the excavators were able to access the cutblocks in various locations (Figure 3). The most difficult area was along the road at the adverse sections of Cutblock 13, where the fill slopes were consistently steep. Loaders are highly mobile machines that can traverse a wide variety of terrain, and can use their grapple to help stabilize the machine on steep or difficult ground (MacDonald 1999).

The timber extraction routes/trails (Figure 4) are described as a modified up-and-down pattern. Up-and-down and

Figure 3. Loader entering Cutblock 21 at a location with low cutbank height.

[1] S5 and S6 classifications are streams without fish and are not community watershed streams. Class S5 streams are >3 m wide, and S6 streams are <3 m wide.

Figure 4. Cutblock maps showing the timber extraction routes for the loader-forwarding portions of the cutblocks.



serpentine working patterns have been used successfully where the forwarding distance and terrain permit (Andersson and Jukes 1995; Phillips 1996). There was no attempt to forward the stems using a serpentine pattern during this study. Machine travel within the cutblocks was typically perpendicular to the contours, except when ground obstacles such as large boulders, or steep terrain features such as ridges, altered direction of travel. Trees were felled parallel to the contours, as for a cable yarding operation.

Loader-forwarding trails were travelled on more than once. The loaders first rough-bunched and windrowed the stems while forwarding them a short distance. When a continuous length of windrowed stems was prepared, the loaders forwarded these stems to roadside and then prepared the next wood further along the travel route. This resulted in more machine travel closer to the haul road than at the back of the cutblock. Preparing and forwarding the stems into windrowed bunches was more time consuming than forwarding the prepared windrows.

When forwarding the windrowed stems, the loaders were positioned between the stems and the road, 10 m (i.e., full reach) from the stems. This allowed the machines to forward the maximum distance each time they handled the stems. The loaders grappled up to 7 logs at one time (average 3 to 4), and forwarded them approximately 20 m per pass (Figure 5). Limbs were often knocked off during the multiple handling, leaving a random brush mat within the cutblock. As well, limbs were removed by holding a stem loosely in the grapple and sliding the grapple along the length of the stem.

Figure 5. Loader-forwarding showing numerous stems per pass.

Figure 6. Loader-forwarder working near a riparian management zone to extract stems from between the residual saplings.

Figure 7. Loader-forwarding in the adverse section of Cutblock 13. Note the surface boulders.

The streams within the cutblocks were identified on field maps. One stream in Cutblock 21 and one in Cutblock 13 were buffered. Small-diameter (i.e., less than 17.5 cm dbh) co-dominant trees, saplings, and advanced regeneration were retained within the riparian management zones to provide streambank stability. Within Cutblock 21, the loaders built a corduroy trail of logs before crossing the in-block stream, and dismantled it after use. The loaders extracted felled trees from within the riparian buffers with minimal damage to the residual trees (Figure 6). Loader-forwarders can work safely around riparian zones without affecting the actual watercourse (MacDonald 1999).

Cutblocks 21 and 24 had favourable forwarding conditions with slopes up to 39% and 41%, respectively. Cutblock 13 contained both adverse and favourable forwarding conditions, with adverse pitches reaching 33% and favourable pitches reaching 39%. On occasion, the smaller and lighter Kobelco SK 220-LC was utilized on the steeper pitches, as the larger machines tended to slip downhill while maneuvering to reach these areas.

Boulders up to 2.8 m in diameter were present throughout all three cutblocks, and hindered machine travel (Figure 7). Angular colluvium was beneath and near the surface of the cutblocks. The combination of continued track movement, maneuvering around boulders, and the summer heat (up to 35°C) caused the machines to overheat or become very close to overheating. When this occurred, the operator stopped to allow the machine to cool down and left the engine either idling or turned off completely.

Study methods

The shift-level data were collected daily from the three loaders and were used to obtain total scheduled machine hours (SMH) for the forwarding and loading phases. Harvest volumes were supplied by Ainsworth and presented with SMH to show productivities. The loader-forwarding and loading times were combined during the shift-level data collection. Therefore, productivity calculations include both loader-forwarding and loading.

Loader-forwarding cycles were detail-timed throughout the study, and included samples from all three cutblocks representing both adverse and favourable forwarding (see Appendix I for definitions of timing elements). Factors affecting the performance of the loader-forwarding were recorded.

Timber extraction and loading productivities were generated using shift-level and detailed-timing study methods. The hourly machine costs were calculated using FERIC's standard machine costing method (Appendix II) and were used to generate a cost per harvested volume.

Following harvesting, the three cutblocks were surveyed to estimate the proportion of site occupied by the loader-forwarding trails. A randomly oriented grid was superimposed over the entire loader-forwarding area of the three study sites. Grids 35 m by 35 m were used on Cutblocks 21 and 24, and 50 m by 50 m on Cutblock 13. At each plot centre, two perpendicular random line transects were established, and ground characteristics were tallied. Data were summarized as a percentage of total harvested area for each cutblock.

The survey collected data for undisturbed and harvest-generated surface conditions. Harvesting disturbance included primary and secondary loader-forwarding trails, corduroy or stem mat trails, and gouges. The primary and secondary trails were further classified as being compressed slash, mixed organic, exposed mineral, or exposed colluvium. Primary and secondary loader-forwarding trails are described by the following attributes:

- Primary trail: Evidence of numerous machine passes. Travel paths for both machine tracks are continuous and easily followed for at least 4 m from the transect sample area, with obvious track impressions and a mound between the two track locations. These trails would have had an estimated 6 to 15 passes and were often located within 50 to 75 m of the haul road and decking area (Figure 8).
- Secondary trail: Less heavily travelled extensions of the primary trails, and not always obvious if observed independent of the approaching track path. Only one track path may be present, and the mound between track travel paths may not be evident. These trails would have had an estimated 1 to 5 passes, and were often located toward the back of the cutblock as compared to the front.

Figure 8. Primary loader-forwarding trail with researchers standing within each track location.

Results and discussion

Shift-level study

Table 2 summarizes the shift-level results by machine and cutblock. Cutblock 21 was harvested first followed by Cutblocks 24 and 13. The average shift length at Cutblocks 21 and 13 was approximately 9 h, whereas at Cutblock 24 the average shift length was approximately 10 h. Mechanical and non-mechanical delays increased as the study progressed.

The harsh environment (boulders) and resulting wear on the undercarriage caused extended delays, especially within Cutblock 13 where Kobelco SK 300-LC #1 and #2

Table 2. Shift-level summary by cutblock and machine

	Kobelco 300 #1			Kobelco 300 #2			Kobelco 220			All		
	21	24	13	21	24	13	21	24	13	21	24	13
Scheduled shifts (no.)	11	4	24	5	4	22	4	4	23	20	12	69
Scheduled machine hours (h)	102.0	40.0	217.0	44.0	41.5	195.0	37.0	40.0	208.5	183.0	121.5	620.5
Average shift length (h)	9.3	10.0	9.0	8.8	10.4	8.9	9.3	10.0	9.1	9.2	10.1	9.0
Mechanical delays (h)	0.0	2.5	15.0	4.0	1.3	29.5	0.0	0.0	1.0	4.0	3.8	45.5
Non-mechanical delays (h)	0.0	2.0	1.0	0.0	3.7	15.2	1.0	3.5	18.0	1.0	9.2	34.2
Service and other (h)	5.0	0.5	9.0	2.0	0.5	4.0	2.0	0.5	9.5	9.0	1.5	22.5
Productive machine time (h)	97.0	35.0	192.0	38.0	36.0	146.3	34.0	36.0	180.0	169.0	107.0	518.3
Availability (%)	100	94	93	91	97	85	100	100	99.5	98	97	93
Utilization (%)	95	88	88	86	87	75	92	90	86	92	88	84

waited a total of 14 shifts for undercarriage and turntable parts. These 14 shifts were not included in scheduled machine time.

The productive machine time is generated from the scheduled machine time less mechanical, non-mechanical, servicing, and other downtime (including meals). Delays greater than 15 minutes were recorded within the shift-level data. Availability and utilization decreased as the harvesting progressed.[2]

Table 3 shows the productivites for all three machines working together to complete the combined phases of loader-forwarding, processing and loading in the loader-forwarding system. The production per SMH was highest for Cutblock 21 (first harvested), and lowest for Cutblock 24. Production per PMH was highest for the last cutblock harvested. The loader-forwarding technique likely improved over time and Cutblock 13 had a larger piece size and higher volume per hectare. Using an average shift length of 9.2 h for all three cutblocks gives an average productivity of 265 m^3/loader-forwarding system shift.

The process of the three loaders loader-forwarding the stems to roadside, the landing bucker processing the stems, and the haul trucks being loaded cost an average of $15.20/$m^3$.

Detailed timing

Results of the detailed-timing study are summarized in Table 4. The numbers shown for "all 3 machines" are weighted averages. These are heavily influenced by Kobelco SK 300-LC #2 which had 22 h of the 26 h total timing samples. The swing empty cycle element was consistently the shortest of all the elements.

On average, for every 5.6 times a machine handled wood and swung empty, the machine moved, and for approximately every five moves there was a delay. Using the calculated ratios, an average time of 5.1 minutes was required to move 20 logs a distance of 20 m, including a delay of 1 minute.

Figure 9 shows the proportion of time each machine spent within the detailed-timing cycle elements. On average, the machines spent four-fifths of the time performing a productive function (move, swing empty, or handle wood), and the remaining time in delays.

Soil disturbance

Cutblock 13 had proportionately the least amount of total trail area at 9.3%, and Cutblock 21 had the most at 11.3% (Table 5). In this study, the more heavily used primary trails occupied less area than the secondary trails. The primary trail occupied up to a

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

Table 3. Productivities and costs for loader-forwarding, processing, and loading (loader-forwarding system) [a]

	Cutblock 21	Cublock 24	Cutblock 13	All 3 cutblocks
Scheduled machine hours (SMH)	183	121.5	620.5	925
Productive machine hours (PMH)	169	107	518.3	794.3
Volume harvested (m^3)	1 861	1 014	6 033	8 908
Productivity				
m^3/SMH	10.2	8.3	9.7	9.6
m^3/PMH	11.0	9.5	11.6	11.2
m^3/average loader-forwarding system shift	281	252	262	265 [b]
$/$m^3$ (based on SMH)	14.23	17.57	15.09	15.20

[a] Differences due to rounding.
[b] Average shift length for all three cublocks is 9.2 h.

Table 4. Summary of detailed timing showing the average element time per occurrance

	Handle wood (min)	Swing empty (min)	Move (min)	Delay (min)	Total timed (h)
Kobelco SK 300-LC #1	0.36	0.13	1.12	5.81	2.5
occurrence	170	166	44	3	
Kobelco SK 300-LC #2	0.31	0.16	1.60	4.62	22.1
occurrence	1 434	1 432	240	59	
Kobelco SK 220-LC	0.23	0.12	1.44	0.87	1.2
occurrence	108	108	23	1	
All 3 machines	0.31	0.15	1.52	4.62	25.8
occurrence	1 712	1 706	307	63	
ratio [a]	5.6	5.6	1	0.21	

[a] Ratio describes the number of handles, swings, and delays per move.

Table 5. Proportion of cutblock occupied by loader-forwarding trails

Soil surface conditions	Proportion of cutblock area affected (%) [a] Cutblock 21		Cutblock 24		Cutblock 13	
Primary trail	1.7	(0.8)	2.4	(1.1)	1.3	(0.6)
Primary trail with exposed mineral	0.6		1.4		0.0	
Secondary trail	9.7	(2.2)	7.0	(1.3)	8.0	(1.3)
Secondary trail with exposed mineral	0.5		2.2		<0.1	
Total trail	11.3	(2.4)	9.5	(1.5)	9.3	(1.4)
Total trail with exposed mineral	1.1		3.6		<0.1	
Gouge [b]	0.1		0.2		0.1	
Undisturbed	88.6	(2.4)	90.3	(1.4)	90.6	(1.3)

[a] Means for the variables of interest are presented with standard errors shown in parentheses. Differences due to rounding.
[b] Gouges are surface conditions where the machines' grapple or the end of a log have indented or dispersed the forest floor into mineral soil during the harvesting activity.

Figure 9. Proportion of time spent within each detailed-timing cycle element.

quarter of the total trail area by cutblock. Undisturbed portions of the cutblocks accounted for 89 to 91% of the cutblock area. By comparison, Kosicki (2001) reported that 20.4% of a tandem loader-forwarding and clambunk skidding harvested cutblock was occupied by trails.

The amount of exposed mineral soil within the trails varied by cutblock, from less than 1% to 4%. Exposed mineral soil was not a criterion for primary and secondary trail classification. Within the continuous impressions of the primary trails, exposed mineral soil was not prevalent, but there was usually a mat of compressed slash. The operators were careful not to spin the machine tracks, and therefore minimized the churning of the soil.

Although the survey was not done to measure compliance with the Forest Practices Code (FPC), the primary trails can be considered 100% disturbed by FPC definition (either dispersed trail: wheel/track rut or dispersed trail: repeated machine traffic [BCMOF and BC Environment 2001a, 2001b]). About one-third of the secondary trails would correspond to the dispersed trail: repeated machine traffic disturbance. This equates to 4–5% total soil disturbance for each cutblock. All three cutblocks are within the maximum acceptable disturbance levels specified in their silviculture prescriptions.

The entrance and exit locations of the cutblocks were utilized and travelled over many times, and were subject to soil churning and scalping. The loader operators were careful to reduce this disturbance by using their grapples to assist the machines' movement while carefully engaging the tracks.

Conclusions

Operators that had no experience with loader-forwarding were able to forward tree-length stems to roadside using 25- and 33-tonne loaders, within areas of a clearcut block designed for cable yarding, at a cost of \$15.20/m^3 which included processing and loading. The loaders forwarded the stems for a maximum distance of 155–205 m, on slopes up to 41% favourable and 33% adverse. Productivity averaged 265 m^3/average loader-forwarding system shift (three machines harvesting three cutblocks including processing and loading). Loader-forwarding was new to the crew and some time was required to learn the technique.

Availability of the loader-forwarding machines averaged 98% in the first harvested cutblock, and declined to 93% in the last cutblock. Utilization averaged 92% in the first harvested cutblock, and also declined in the last cutblock, to 84%. Detailed timing showed delays accounted for nearly one-fifth of the productive machine time.

The bouldery conditions were thought to have caused one of the machines to lose its track and initiate the extended wait-for-part delay. Undercarriage repairs and delays may occur more frequently during loader-forwarding operations than compared to typical loading duties.

Results of the soil disturbance survey showed that loader-forwarding trails occupied 9–11% of the cutblock area, and when extrapolated to FPC standards for soil disturbance, the three cutblocks were all within their stated acceptable limits.

Implementation

During the study, FERIC identified conditions for successful and efficient use of loader-forwarding operations:

- Thirty-five-tonne loaders can forward stems within clearcut blocks with slopes up to 41% favourable and 33% adverse. These slopes may be close to the limits for this size of machine. The 25-tonne loader was able to negotiate the 41% favourable slope slightly easier than the larger machines.
- Using a feller-buncher to fall and bunch the harvested stems may be beneficial with respect to productivity. The loaders spent more time preparing and forwarding the stems into windrowed bunches than forwarding the prepared bunches.
- Terrain with large or numerous boulders should be noted when field layout is done. Split lines can divide areas between those compatible with loader-forwarding and those for cable yarding. The boulders encountered during this study were hard on the machines and were thought to be a main source of the gradual decline in availability and utilization.

- Locations where the machines enter and exit the cutblocks are vulnerable to site disturbance. The best locations to enter and/or exit the cutblock may be identified during planning and marked after road construction. Protective matting, chunks of wood, or corduroyed stems may also lessen the impact at these locations.

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Appendix I

Cycle elements for detailed timing of loader-forwarding operation

Handle wood:	Begins when "swing empty" is finished and grapple is used to grasp logs to be forwarded, and ends when grapple releases log(s). Includes bunching and double handling to make neat windrowed decks within the cutblock, re-handling dropped pick-ups, positioning grapple after swing empty stops, aborted handles, and handling wood while moving.
Swing empty:	Begins when "handle wood" or "move" stops. Typically occurs after each handling of a forwarded grapple of stems. There is no track movement during "swing empty". Includes turning machine 360° to look for appropriate placement of machine.
Move:	Begins when tracks are engaged and the loader travels or re-positions itself (with an empty grapple). Includes moving obstacles in the path of machine travel, pushing heel of grapple into the ground to lift and twist the tracks, and preparing travel path over streams and boulders by placing logs as corduroy trails or lift logs.
Delay:	Begins when a productive element is interrupted and ends when a productive element is recommenced. Includes mechanical and personnel delays.

Appendix II

Cost estimates for loader-forwarding equipment [a]

	Loader 25 000–30 000 kg Kobelco SK 220-LC	Loader 30 000–35 000 kg Kobelco SK 300-LC
OWNERSHIP COSTS		
Purchase price (P) $	380 000	490 000
Ownership period (D) y	5	5
Scheduled hours per year (h) h	1 800	1 800
Salvage value as % of P (s) %	33	33
Interest rate (Int) %	9.0	9.0
Insurance rate (Ins) %	3.0	3.0
Salvage value (S)=(P•s/100) $	125 400	161 700
Average investment (AVI)=((P+S)/2) $	252 700	325 850
Loss in resale value ((P-S)/(D•h)) $/h	28.29	36.48
Interest=((Int•AVI)/h) $/h	12.64	16.29
Insurance+((Ins•AVI)/h) $/h	4.21	5.43
Total ownership costs (OW) $/h	45.14	58.20
OPERATING AND REPAIR COSTS		
Fuel consumption (F) L/h	25	30
Fuel cost (fc) $/L	0.55	0.55
Lube and oil cost as % fuel cost (fp) %	10	10
Track & undercarriage life (h)	4 500	4 500
Track & undercarriage replacement cost (Tr) $	28 000	32 000
Annual operating supply cost (Op) $	5 000	5 000
Annual repair and maintenance cost (Rp) $	35 000	40 000
Wages (W) $/h		
Machine operator base rate	24.01	24.01
Total machine operator rate	24.01	24.01
Wage benefit loading (WBL) %	38	38
Fuel cost (F•fc) $/h	13.75	16.50
Lube and oil cost ((fp/100)•(F•fc)) $/h	1.38	1.65
Track and undercarriage cost (Tr/h) $/h	6.22	7.11
Operating supply cost (Op/h) $/h	2.78	2.78
Repair and maintenance cost (Rp/h) $/h	19.44	22.22
Labour cost (W•(1+WBL/100)) $/h	33.13	33.13
Total operating and repair costs (OP) $/h	76.70	83.39
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	121.84	141.59

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs, and do not include such costs as crew transportation, supervision, profit, and office overhead. IWA labour rates effective June 15/99 have been used. Note: Costs per hour for the landing bucker are calculated using IWA labour rates, 38% wage beneifit loading, and $18/day saw allowance, equalling $35.13.