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ANALYSIS OF A SKYLINE PARTIAL CUTTING OPERATION IN THE INTERIOR CEDAR–HEMLOCK BIOGEOCLIMATIC ZONE

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Abstract

In 1997, the Forest Engineering Research Institute of Canada (FERIC) studied a partial cutting operation in the Interior Cedar-Hemlock biogeoclimatic zone, on a site west of Kitwanga, B.C. The operation used a Skylead C40 16000 skidder-mounted yarder and Mini-Maki II radio-controlled carriage in a standing skyline configuration and in single- and multi-span applications. The study provided information on productivity and cost for the harvesting system, impact on soil surface conditions, and damage to the residual stand. Productivity functions were derived to predict yarding productivities and costs over a range of operating conditions.

Author

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Summary

In 1997, the Forest Engineering Research Institute of Canada (FERIC), in a project funded by Forest Renewal BC, studied a skyline yarding system over short and long yarding distances and with and without intermediate supports. The study site was an Interior Cedar–Hemlock stand near Kitwanga, B.C. The operation used a Skylead C40 16000 skidder-mounted yarder and a Mini-Maki II radio-controlled carriage in a standing skyline configuration. Partial cutting employing a combination of narrow strip-cuts and group selection was prescribed for the study site to address visual, recreational and silvicultural objectives.

The yarding pattern applied in the block consisted of parallel yarding corridors spaced approximately 50 m apart and oriented perpendicular to the contours. To accommodate the skyline system, a 10-m-wide corridor was clearfelled and group-selection or occasionally single-stem removals were applied to the 40-m-wide strips of residual stand between yarding corridors. A target removal of 40% was set for this entry, with future entries at about 30-year intervals removing up to 30% of the stand basal area and volume at each subsequent entry.

FERIC assessed the economic and operational feasibility of the harvesting system used and determined the overall productivity and cost for all phases of the operation; developed productivity functions to relate productivity and cost for the yarding phase to external and lateral yarding distances, use of intermediate supports and other significant variables; identified operational factors affecting system performance and recommended improvements where appropriate; documented damage to residual stems and changes to soil surface conditions resulting from falling and yarding activities; and evaluated the visual impact of the harvest.

FERIC found that falling productivity was 99 m^3/shift and yarding productivity was 102 m^3/shift. The total cost for falling, yarding, processing and loading was \$32.95/m^3. The post-harvest survey showed that 5.4% of the residual stand was wounded; no potentially detrimental site disturbance was found in the cable-yarded area.

Operationally, falling was the most critical phase because the placement of stems directly affected yarding productivity and leave-tree damage. This study confirmed that it is essential to have a logging plan that considers all factors including backspar and landing locations, falling pattern and direction, location and loadpath analysis for yarding corridors, and other natural resource values. Clearly defined silvicultural objectives for locating skyline corridors and lateral rows were necessary to fulfil the objectives of this operation, and to minimize the impact of harvesting on stand structure while maximizing economic returns.

Sommaire

En 1997, dans le cadre d'un projet financé par Forest Renewal BC, l'Institut canadien de recherches en génie forestier (FERIC) a étudié un système de téléphérage à câble porteur sur de courtes et de longues distances de téléphérage, ainsi qu'avec et sans pylônes intermédiaires. L'aire d'étude était située dans un peuplement de cèdre-pruche de la zone intérieure, près de Kitwanga, C.-B. On utilisait un câble-grue Skylead C40 16000 monté sur débardeur, et un chariot Mini-Maki II télécommandé dans une configuration de câble porteur à tension fixe. Une coupe partielle combinant des coupes par bandes étroites avec un jardinage par bouquets était prescrite pour l'aire d'étude, afin de satisfaire à des objectifs visuels, récréatifs et sylvicoles.

Le schéma de téléphérage appliqué dans le bloc consistait en corridors de téléphérage parallèles, espacés approximativement aux 50 m et orientés perpendiculairement aux courbes de niveau. Pour permettre l'installation du téléphérique, un corridor de 10 m de largeur était coupé à blanc, et on procédait au jardinage par bouquets et occasionnellement au prélèvement d'arbres individuels dans les bandes résiduelles de 40 m de largeur entre les corridors de téléphérage. L'objectif de prélèvement était fixé à 40 % pour cette coupe, avec des coupes futures à intervalles d'environ 30 ans pour enlever jusqu'à 30 % de la surface terrière et du volume du peuplement à chaque passage subséquent.

L'étude de FERIC consistait à évaluer la faisabilité économique et opérationnelle du système de récolte utilisé et à déterminer la productivité et le coût d'ensemble pour toutes les phases de l'opération; à développer des fonctions de productivité pour établir les relations entre la productivité et le coût de la phase de téléphérage d'une part, et les distances externes et latérales de téléphérage, l'utilisation de pylônes intermédiaires et d'autres variables significatives d'autre part; à identifier les facteurs opérationnels affectant la performance du système et à recommander des améliorations quand c'était approprié; à documenter les dommages aux tiges résiduelles et les changements aux conditions de la surface du sol résultant des activités d'abattage et de téléphérage; et à évaluer l'impact visuel de la récolte.

FERIC a trouvé que la productivité à l'abattage était de 99 m³/poste de travail et la productivité au téléphérage de 102 m³/poste. Le coût total pour l'abattage, le téléphérage, le façonnage et le chargement s'élevait à 32,95 $/m³. L'évaluation après coupe a révélé que 5,4 % des arbres résiduels présentaient des blessures; aucune perturbation potentiellement nuisible du site n'a été constatée dans l'aire de téléphérage.

Au plan opérationnel, l'abattage était la phase la plus critique parce que la position des tiges affectait directement la productivité du téléphérage et les dommages aux arbres résiduels. Cette étude a confirmé qu'il est essentiel d'avoir un plan d'exploitation tenant compte de tous les facteurs, y compris l'emplacement des pylônes arrière et des jetées, le schéma et la direction d'abattage, l'analyse de l'emplacement des corridors de téléphérage et du trajet suivi par la charge, ainsi que d'autres valeurs liées aux ressources naturelles. Des objectifs sylvicoles clairement définis en situant les corridors du câble-grue et les allées latérales ont été nécessaires pour satisfaire aux objectifs de cette opération et réduire au minimum l'impact de la récolte sur la structure du peuplement tout en maximisant la rentabilité économique.

INTRODUCTION

Forest management practices in British Columbia are changing rapidly to better accommodate the management of non-timber resources. Partial cutting prescriptions are encouraged, and in some cases required, to meet these management goals. Experience with partial cutting is still limited for many of British Columbia's forest ecosystems, and research is needed to learn how to conduct efficient harvesting operations under these regimes. In this operational trial, performed by Kitwanga Lumber Co. Ltd., the Forest Engineering Research Institute of Canada (FERIC) examined the performance of a skyline yarding system in a partial cut in an Interior Cedar–Hemlock (ICH) stand. FERIC observed the system over short and long yarding distances, and with and without intermediate supports.

The site for this trial was located at Wilson Creek, 22 km west of Kitwanga, B.C. Partial cutting employing a combination of narrow strip-cuts and group selection was prescribed for the study site to address visual, recreational and silvicultural objectives. Portions of the cutblock are visible from Highway 16 and the Visual Quality Objective (VQO) for the site is Partial Retention. Hiking opportunities and the presence of a heritage trail nearby also favoured partial retention.

Although literature about partial cutting is abundant (Daigle 1995), the ICH biogeoclimatic zone is not well represented. Trials near Kispiox, B.C. of ground-based harvesting systems (grapple skidders, line skidders and horses) in clearcut, heavy-removal and light-removal silvicultural treatments were documented by Thibodeau et al. (1996) for the same ecosystem as this study (ICHmc2). However, the application of cable yarding systems in partial cutting prescriptions in the ICH zone has not yet been studied. Also, while the yarder and carriage used in this trial have been studied in other ecosystems (Forrester 1993a, b; Hedin and DeLong 1993), it is not clear how reliably the results of these studies can be extrapolated to the ICH zone. This study addresses this particular information gap.

This project was funded by Forest Renewal BC and addresses one of its strategic investment priorities under its Land and Resource Research program, that of partial cutting. This study contributes information to the forest industry in its continuing effort to develop economically feasible and biologically acceptable harvesting practices for partial cutting prescriptions for the full range of site and stand conditions in British Columbia.

OBJECTIVES

The primary goal of this study was to assess the economic and operational feasibility of using a skyline-yarding system for partial cutting in an ICH stand. The following specific objectives were established to address this goal:

- Determine overall productivity and cost for the falling, yarding, processing and loading phases of the partial cutting operation.
- Analyze the effects on yarding productivity of external and lateral yarding distances, of using single skyline spans (no intermediate supports) and multiple spans (one or more intermediate supports), and of other site and stand variables.
- Develop productivity functions to relate productivity and cost for the yarding phase to external and lateral yarding distances, use of intermediate supports, and other significant variables.
- Identify operational factors affecting system performance and recommend improvements where appropriate.

Although a full evaluation of the biological and aesthetic implications of the harvest prescription was beyond the scope of this study, the following secondary objectives were set to provide information on these topics:

- Document damage to residual stems and changes to soil surface conditions resulting from falling and yarding activities.
- Illustrate the visual impact of the operation by photographing from selected viewpoints, the cutblock before, during and after harvesting.

SITE AND STAND DESCRIPTIONS

The study site was located in the Kispiox Timber Supply Area, between Wilson and Duncan Creeks on the north side of the Skeena River (Figure 1). Of the total cutblock area of 79.2 ha, 48.7 ha were skyline-yarded, 14.4 ha were skidded with low ground pressure skidders, and 16.1 ha were in reserves and deferred areas. The skyline-yarded area included 6.0 ha of haul roads, landings and rock-pits, leaving a net area of 42.7 ha.

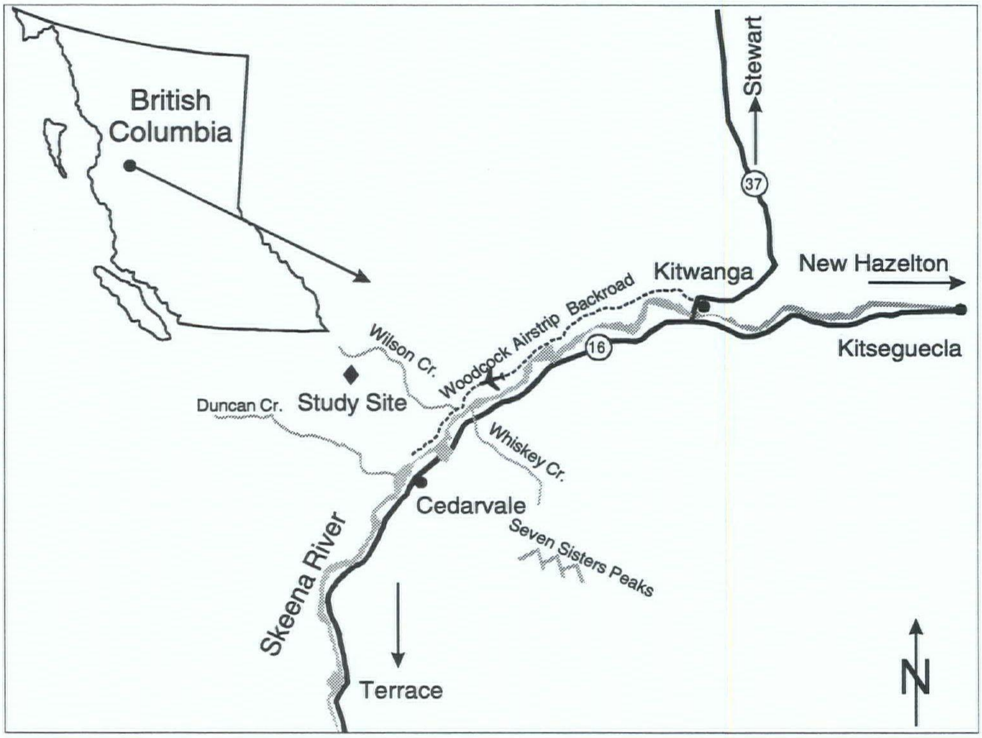

Figure 1. Location of study site.

The 130-year-old, fire-origin stand, within the Hazelton variant of the Interior Cedar–Hemlock Moist Cold subzone (ICHmc2) (Banner et al. 1993), contained western red cedar (*Thuja plicata* Dougl. ex D.Don), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), hybrid spruce (*Picea sitchensis* var. *glauca*), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), paper birch (*Betula papyrifera* Marsh.), and trembling aspen (*Populus tremuloides* Michx.), plus amabilis fir (*Abies amabilis* [Dougl.] Forbes) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa* Torr. & Gray) at lower elevations. Two timber types occurred within this treatment (Table 1). Type I, a dense small-diameter cedar–hemlock stand, occupied the lower part of the block. Type II, a larger diameter, less dense hemlock–balsam stand, occupied the upper part of the block.

Topography was relatively steep and broken, with frequent benches throughout the area. In the skyline unit, slopes ranged from 10 to 60% and averaged 32%. The elevation ranged from 440 to 680 m.

Silvicultural Prescription

The long-term management objectives for this site were to:

- Develop and maintain a mosaic of all-aged and even-aged stands, composed of multiple species with a diversity of age and height classes.

- Retain a portion of the existing stand in unlogged reserves for wildlife trees, snags and coarse woody debris.

- Establish and grow a continuous crop of sawlogs that will produce approximately 300 m^3/ha over a 100-year rotation.

To achieve these goals, a group-selection system was prescribed. A target removal of 40% was set for this initial entry, with future entries at about 30-year intervals each removing up to 30% of the stand basal area and volume. The target of 40% was chosen to open the stand and promote recruitment of natural regeneration while maintaining windfirmness. The silvicultural prescription was to plant western red cedar, subalpine fir, hybrid spruce and lodgepole pine at a density of 1000 trees per hectare, with natural regeneration to complement planted stock. The artificial regeneration option was selected to minimize the ingress of western hemlock.

HARVESTING SYSTEM AND OPERATION

The yarding pattern applied in this study consisted of parallel yarding corridors spaced approximately 50 m apart and oriented perpendicular to the contours (Figure 2).

Table 1. Average Pre-harvest Stand Characteristics

	Species							
	Western red cedar	Western hemlock	Subalpine fir	Hybrid spruce	Lodgepole pine	Paper birch	Trembling aspen	Total
Type 1 (18.0 ha)								
Net merch. vol./ha (m^3)	125	157	54	68	23	7	7	441
Trees/ha (no.)	267	219	75	32	44	16	17	670
Average dbh (cm)	28.3	31.4	29.5	46.6	27.9	29.7	31.6	30.7
Ave. net merch. vol./tree (m^3)	0.47	0.72	0.73	2.15	0.53	0.43	0.42	0.66
Type II (24.7 ha)								
Net merch. vol./ha (m^3)	100	314	107	161	30	1	4	717
Trees/ha (no.)	197	470	114	76	33	3	16	909
Average dbh (cm)	31.9	30.4	32.8	46.9	33.6	35.5	27.4	32.9
Ave. net merch. vol./tree (m^3)	0.51	0.67	0.94	2.12	0.9	0.46	0.23	0.79
Total treatment (42.7 ha)								
Net merch. vol./ha (m^3)	111	248	85	122	27	4	5	602
Trees/ha (no.)	226	364	97	57	38	8	17	807
Average dbh (cm)	30.4	30.8	31.4	46.8	31.2	33.1	29.2	32.0
Ave. net merch. vol./tree (m^3)	0.49	0.69	0.85	2.13	0.74	0.45	0.31	0.74

To accommodate the skyline system, 10-m-wide yarding corridors (5 m on either side of the skyline) were clearfelled. Group-selection or, occasionally, single-stem removals were applied to the 40-m-wide strips of residual stand between yarding corridors. Corridor locations were determined by the engineering crew, and the centreline of each corridor was flagged (corridor boundaries were also flagged on a few corridors). Also, backspar and intermediate support trees were selected and marked while corridors were being located.

Description of Harvesting Phases

For the first two weeks, two fallers experienced in partial cutting were used. Thereafter, only one of them worked on the site. At the start of each corridor, the faller did a reconnaissance of the corridor centreline and measured 5 m on each side of it to determine its boundaries. The faller felled both the corridor and small pockets of 1 to 5 trees off the corridor in a one-pass operation. Stumps were cut low to the ground and on an angle, to minimize hangups during yarding. No delimbing or bucking was done in the bush, except for very large trees.

Tables showing the existing and residual stand structure and the planned cut for each timber type were given to the faller by the forestry superintendent, as well as suggestions on how to select trees within pockets.

The cable-yarding operation was configured as a standing skyline and employed a small tower yarder and radio-controlled carriage. The yarder was a Skylead C40 16000 skidder-mounted machine with a 12.2-m tower (Figure 3), powered by a 124-kW Cummins engine, and used a 19-mm (3/4") swaged skyline and 13-mm (1/2") IPS mainline. The yarding crew was comprised of a yarder operator, a chaser and one or two chokersetters.

A Mini-Maki II motorized radio-controlled carriage was used (Figure 4). This is a clamping-type carriage, which can be locked to the skyline adjacent to the turns to be yarded. The carriage's on-board 6.7-kW motor powers a capstan which feeds slack from the mainline, and the chokersetters can then pull the chokers laterally to the hook-up site. When the turn is hooked, the chokersetter signals the yarding engineer to draw the turn laterally towards the skyline corridor. Once the turn is suspended under the carriage, the clamp is released and the carriage and turn are yarded to the landing. This carriage can tolerate changes in direction of up to 8 degrees in horizontal (plan) alignment of the skyline when yarding over intermediate supports.

A Hitachi EX 270 LL log loader (Figure 5) worked with the yarder to clear the landing and also to load trucks from decks of processed logs. This often required the loader to travel long distances, as relatively small piles of logs were widely dispersed along the haul roads. In some cases, yarder-assisting and truck-loading activities conflicted, resulting in delays in loading trucks or in clearing the landing for the yarder. In the latter case, large piles of logs accumulated under the skyline, which made unhooking of turns difficult and time-consuming.

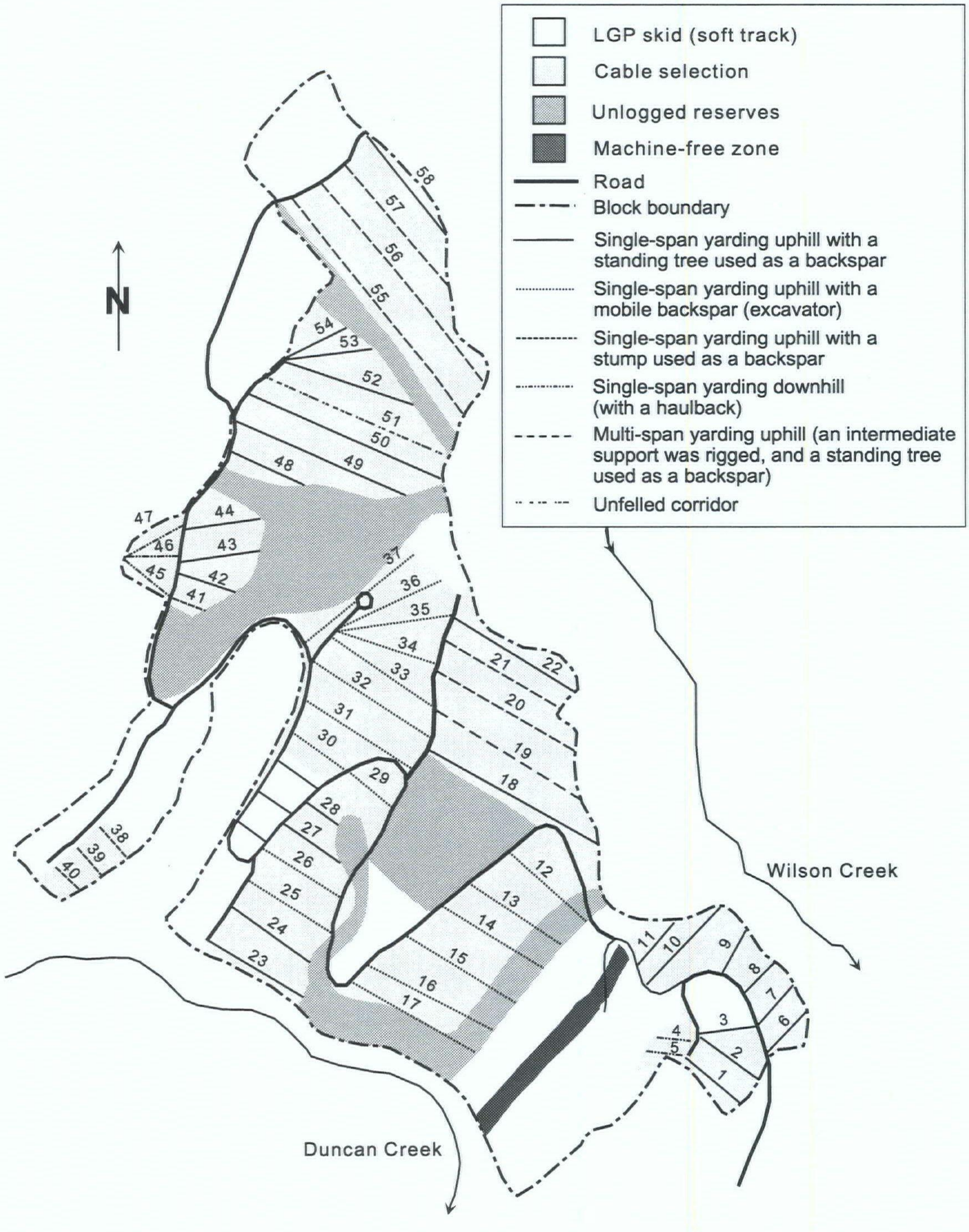

Figure 2. Logging map of the cutblock.

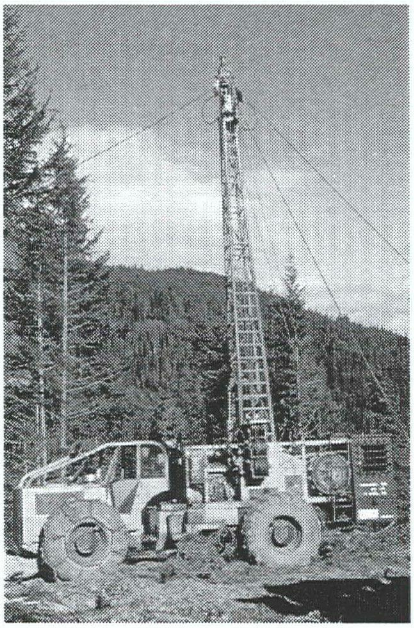

Figure 3. The Skylead C40 16000 yarder used in this operation.

Figure 4. Mini-Maki II carriage after passing the intermediate support.

Occasionally, a Clark Ranger 668 grapple-skidder was used to clear the landing when the loader was not available.

Logs were mechanically processed at roadside, initially by a wheeled Timberjack processor equipped with a Denis head, and later by a Pierce processor mounted on a Hyundai 290 LC tracked undercarriage. The loader

Figure 5. Loader clearing the landing during yarding.

and processor worked in both the ground-skidded and cable-yarded areas of the cutblock. Company highway trucks hauled the logs to the Kitwanga Lumber Co. Ltd. mill, approximately 20 km from the study site.

Rigging Systems Used in the Study

A variety of rigging configurations was used to deal with the variable terrain conditions and yarding distances in the cable-yarded portion of the cutblock (Figure 2 and Table 2). The most frequently used configuration was single-span yarding uphill with a standing tree used as a backspar (i.e., gravity skyline or shotgun), which accounted for 39% of total corridor length.

The layout presented in Figure 2 was respected, except Corridor 51 could not be used because the designated intermediate support was not considered satisfactory. To compensate, lateral corridors aligned in a herringbone pattern were felled and yarded from Corridors 50 and 52.

For single-span yarding uphill (with fixed or mobile backspars), corridor lengths ranged from 40 to 350 m. For multi-span yarding, lengths ranged from 200 to 420 m. The average external yarding distance was 65 m for single-span yarding and 146 m for multi-span yarding. Lateral yarding distances ranged from 0 to 50 m.

Where yarding roads terminated at a haul road (33% of total corridor length), a Caterpillar EL 300 excavator was used as a mobile backspar (Figure 6) and this reduced the rigging time for corridor changes. Multi-span yarding was required on only 6 corridors but these accounted for 21% of total corridor length. Stumps were used as tailholds on short uphill-yarding corridors (3% of corridor length), and the haulback line had to be used to permit downhill yarding on 5 short corridors (4% of total corridor length).

Table 2. Rigging Configurations Used in the Block

Method	Corridors (no.)	Corridor length (m)	(%)
Single-span yarding uphill with a standing tree used as a backspar	25	3296	39
Single-span yarding uphill with a mobile backspar (excavator)	17	2830	33
Single-span yarding uphill with a stump used as a backspar	4	240	3
Single-span yarding downhill (with a haulback)	5	310	4
Multi-span yarding uphill (an intermediate support was rigged, and a standing tree used as a backspar)	6	1760	21
Total	57	8436	100

Figure 6. Excavator used as a mobile backspar.

Figure 7. Nylon guyline strap with self-tensioning clamp.

Backspar trees were rigged with three (or occasionally four) guylines. The guylines were 102-mm-wide, double-ply nylon straps with self-tensioning clamps (Figure 7), and were attached to the backspar between 0.5 and 1.5 m above the tree-strap rigging point. Rigging heights on the backspar trees varied from 8 to 15 m, depending on deflection requirements and available support trees. The diameter at breast height (dbh) of the backspars ranged from 40 to 60 cm.

Intermediate supports were also rigged with three nylon-strap guylines. Like the backspars, these were attached between 0.5 and 1.5 m above the tree-strap rigging point. To support the skyline jack, a tree block was hung on the tree strap. The snake (i.e., the line that supports the skyline jack) passed through the tree block, then back to a tailhold tree perpendicular to the yarding corridor and opposite the guylines (Figure 8). The snake was then tensioned with a grip puller to raise the skyline jack into its working position and to pull it away from the intermediate support to provide yarding clearance. Intermediate supports were pre-rigged whenever possible.

Construction of landings was minimal in this operation; whenever possible, logs were decked by the roadside.

METHODS

FERIC was on site almost full time for the duration of this study, collecting shift-level and detailed-timing data, evaluating removal levels, and assessing the impact of the harvest on the stand and site. In addition, researchers observed various factors that affected productivity and discussed with crew members possible ways of improving performance. Whenever possible, these results were quantified and presented in the report.

Productivity and Cost of Harvesting

Shift-level and detailed-timing data were used to determine overall production rates for the skyline operation, and to assess the impacts of yarding distance and intermediate supports on yarding productivity. For shift-level analysis, the yarder was

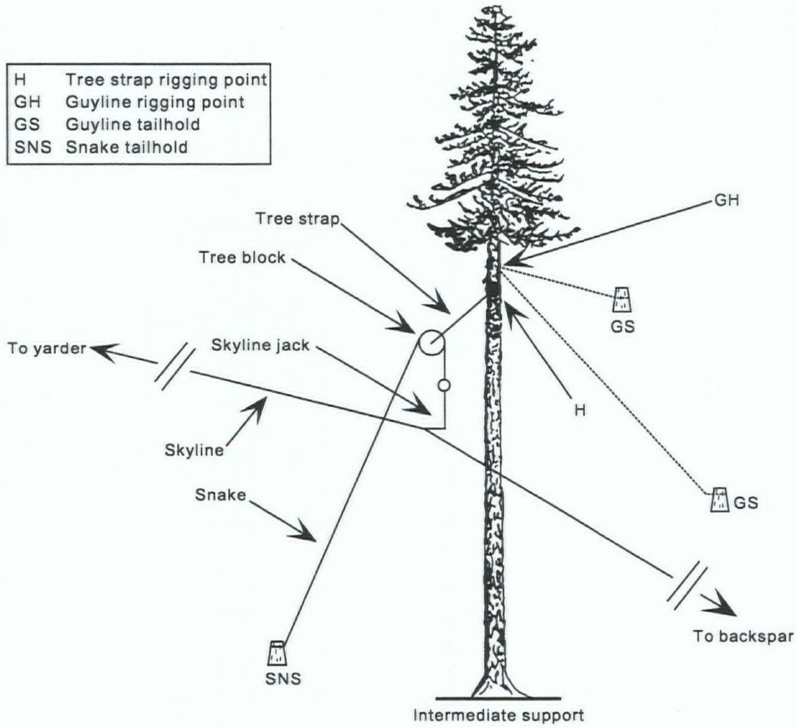

Figure 8. Rigging configuration for intermediate support.

equipped with a DSR Servis Recorder and a supplemental shift-level form was completed daily by all machine operators. The shift-level form collected specific information about the activities performed that day (e.g., yarding road worked on that day and reasons and times of major delays). The faller also completed a shift-level form to document daily activities for the falling phase. These data were compiled to calculate availabilities, productivities and costs for the faller and machines used in this operation.

Twenty-four yarding corridors, representing each of the rigging methods, were selected according to criteria presented by Howard (1988 and 1989), to obtain representative detailed-timing information for single- and multi-span yarding. On the corridors selected, more than 800 yarding cycles (turns) and associated delays were detailed-timed using a hand-held datalogger. For purposes of analysis, the dependent variable was total delay-free cycle time, and the independent variables were slope yarding distance, lateral yarding distance and number of logs per turn. For safety reasons, the volume per turn could not be measured at the landing during logging operations, so the number of logs per turn was chosen as a substitute independent variable. An average turn volume was estimated by multiplying the average number of logs per turn by the average piece volume (from shift-level data and final scaled volumes).

Each harvesting cycle was divided into the following cycle elements: outhaul, lateral out, hookup, lateral in, inhaul and unhook. See Appendix I for definitions of these cycle elements.

The detailed-timing data were analyzed using multiple regression techniques. The relationship between total cycle time and each independent variable was estimated, and a complete model, including all terms, was written for the data. A 0.05 significance level was used to test the relationship and the contribution each term made to the model. The model was reduced using the elimination technique until every independent variable retained was significant. As a final check, a lack of fit test was performed by plotting the residuals. Separate productivity equations were developed for single- and multi-span yarding.

System productivities expressed as volume of timber yarded per hour (m^3/h) and cost per cubic metre ($\$/m^3$) were derived based on shift-level data. Productivity in m^3/SMH (scheduled machine hour) was determined for each phase based on volume harvested and time spent by the faller and each machine in the yarded area. Time distributions showing productive time, time spent for maintenance, moving machine and rigging (for yarder), and delays, were developed for all machines and for the faller. Hourly machine costs were calculated using FERIC's standard costing methodology (Appendix II), and labour costs were calculated using applicable coastal IWA labour rates. These costs do not include supervision, profit, overhead or crew transportation, and do not reflect the actual costs incurred by the company.

Costs for block layout and engineering were estimated from information supplied by the licensee.[1] They do not include supervision costs, and do not include all costs of getting approvals and other paperwork accomplished.

Impact of the Operation on Stand and Site

Plot centres established for the operational timber cruise were relocated and permanently marked in the field. These plots were uniformly distributed throughout the cable-yarding treatment unit (systematic sampling), at a density of approximately one plot per hectare. Within the plots, sample trees were selected with a prism to determine removal level by basal area and to compare it with the original prescription (PPS - Probability Proportional to Size). The intensity of the cut was also assessed with respect to total volume harvested from the cutblock.

The same plots were used to assess site and stand conditions. Assessment of tree injuries (wounds, gouges, etc.) conformed to the standards described in the Tree Wounding and Decay Guidebook (BCMOF; BC Environment 1997) and assumed the stand management objective for the study block is long-term retention. Therefore, a tree was considered not acceptable as a residual crop tree if it met or exceeded the following limits:

- a wound that girdled more than a third of the stem circumference
- a wound exceeding 400 cm^2 on the stem
- a wound on a supporting root within 1 m of the stem
- a gouge in the stem

Post-harvest soil disturbance was assessed by locating two 15-m transects at each plot centre. A random bearing was selected for the first transect and the second one was oriented at 90° to the first. Soil disturbance was sampled at 1-m intervals along each transect line. Each sample point was classified as either disturbed or undisturbed, and surface condition was recorded. A point was considered disturbed if the litter was scuffed or if the mineral soil was exposed by yarding or falling activities; otherwise, it was recorded as undisturbed.

Finally, to supplement information about all phases of the logging process, including rigging of backspars and intermediate supports, FERIC videotaped the harvesting operations periodically.

RESULTS AND DISCUSSION

Kitwanga Lumber Co. Ltd. began harvesting the study site in late May 1997. The harvesting operation continued without interruption throughout the summer and fall, until completion at the beginning of October. Generally favourable weather and higher-than-expected machine availability and production during the study period shortened the harvesting operation significantly from initial forecasts.

Shift-Level Productivity

The total volume harvested from the cable-yarded area was 9650 m^3. A summary of productivity parameters for the entire cutblock and for all phases is presented in Table 3.

Table 3. Summary of Productivity

	Shifts (no.)	Hours (no.)	Shift length (h)	Productivity (m^3/shift)
Faller	84	630	7.5	99[a], 115[b]
Yarder	87	754	8.7	102[c], 111[d]
Loader	69	600	8.7	-
Processor	71	616	8.7	140[d]

[a] For 6.5-h shift.
[b] For 7.5-h shift.
[c] For 8-h shift.
[d] For 8.7-h shift

For all three machines used in this operation, the average shift length was 8.7 h. During most of the operation they worked 9 h/day, but during periods of high fire hazard they worked only 7 h/day.

The faller did not have a rigid daily schedule. Shift length ranged from 6.5 to 9 h/day on the cutblock and averaged 7.5 h/day in the cable-yarded area. The faller felled corridors, road rights-of-way, and some of the small clearcuts in the upper part of the cutblock.

Figure 9 illustrates the distribution of time elements for all machines and people that worked in the cutblocks. For the yarder, changing roads took from 0.5 to 5.5 h.The

[1] Philip Carruthers, Forestry Superintendent, Kitwanga Lumber Co. Ltd., personal communications, February 1998.

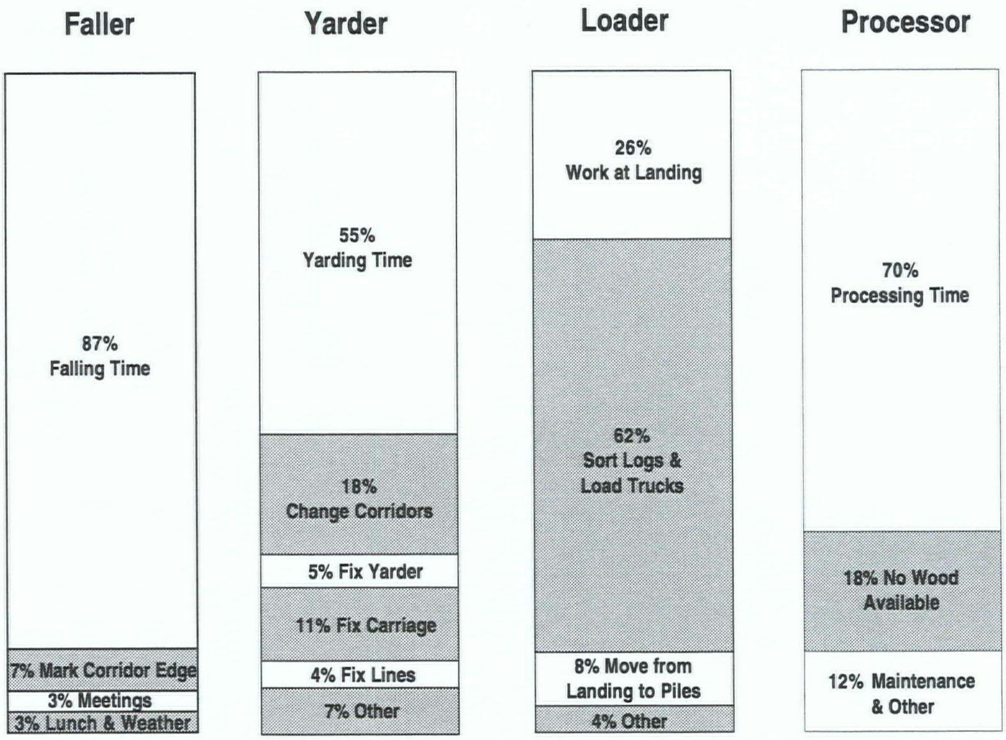

Figure 9. Time distribution: all phases.

time necessary was short when a mobile backspar was used or when stump rigging. Very long rigging times were required when a tree was rigged as a backspar and/or the corridor was very long. Additional time (up to 1.5 hours) was required when an intermediate support was needed, because the grip puller used to tension the snake was a slow device. Line repairs included fixing the skyline when broken; splicing new line into the skyline; tightening guylines on the tail tree, intermediate support and yarder; and changing lines on the machine. Miscellaneous delays took 7% of total time and included waiting for a machine to clear the way when changing roads, time off while waiting for the faller to finish the next corridor, and time to fix the vehicle used by the yarding crew.

Analysis of the processing phase used pooled data for both machines used in the cutblock. Mechanical downtime amounted to about 12% (mainly related to the first processor), and once processing caught up with the yarder, the processor was idle due to lack of wood for about 18% of the time.

Unit Costs

The cost for each phase is presented in Table 4. The loading cost includes all loader activities such as assisting the yarder and sorting logs, as well as loading trucks.

Table 4. Summary of Harvesting Costs by Phase

Description	Cost ($/m^3)
Falling	
Labour	3.42
Saw allowance	0.24
Total falling	3.66
Yarding	
Labour	8.89
Skylead C40 16000 yarder	4.49
Mini-Maki II carriage	0.79
Caterpillar EL 300 (backspar)	0.39
Total yarding	14.56
Loading	
Labour	2.05
Hitachi EX 270 LL log loader	4.76
Total loading	6.81
Processing	
Labour	2.12
Pierce processor	5.80
Total processing	7.92
Total labour cost	16.48
Total machine cost	16.47
Total harvesting cost	32.95

The total harvesting cost, including loading, for the cable-yarding portion of the cutblock was $32.95/m^3$. Including the cost for block layout and engineering ($3.23/m^3$), the total cost was $36.18/m^3$.

Based on the results calculated in this report, a methodology for calculating productivity and cost for other partial cuts is presented in Appendix III.

Yarding Cycle Time

Table 5 presents time elements as a percentage of total cycle time. Figures 10 and 11 present time elements as a percentage of delay-free cycle time.

Table 5. Detailed-Timing Summary of Yarding Cycle Elements

	Single-span [a]		Multi-span [b]	
	Ave. time/ element (min)	Time/ element (%)	Ave. time/ element (min)	Time/ element (%)
Outhaul	0.27	8	0.50	13
Lateral out	0.34	9	0.33	8
Hookup	0.80	22	0.81	20
Lateral in	0.52	14	0.49	12
Inhaul	0.51	14	0.86	22
Unhook	0.81	23	0.83	21
Total delay-free cycle time	3.25	91	3.82	96
In-cycle delays	0.34	9	0.16	4
Total cycle time	3.59	100	3.98	100

[a] Average yarding distance of 65 m.
[b] Average yarding distance of 146 m.

For single-span yarding, hookup and unhook were the most time-consuming elements, each accounting for 25% of delay-free cycle time. For multi-span yarding, inhaul took a larger proportion of cycle time because external yarding distances were longer, and more care was required to pull the carriage over intermediate supports to ensure the skyline did not jump off the jack. The cycle elements "lateral out", "lateral in", "hookup" and "unhook" had similar values for both rigging configurations. Delays accounted for a larger proportion of total cycle time in single-span than in multi-span operation, although the reason is not clear.

Equations 1 and 2 give the delay-free cycle time for single- and multi-span yarding, determined from multiple regression analysis. Significant linear relationships were found between cycle time, slope yarding distance and lateral yarding distance. The number of logs yarded per cycle was not a significant variable.

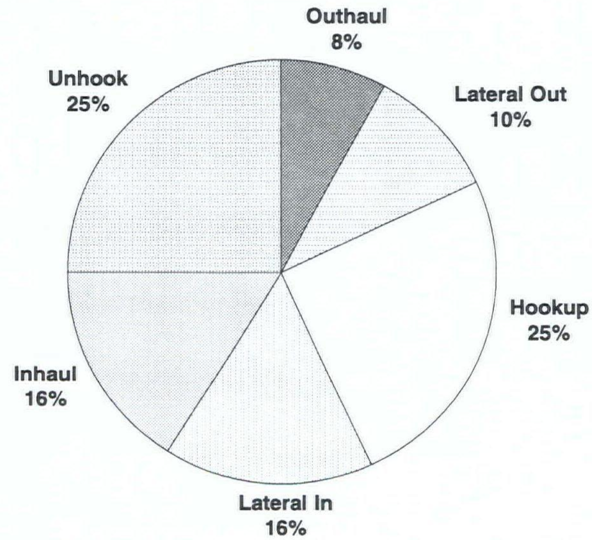

Figure 10. Cycle time distribution: single-span yarding.

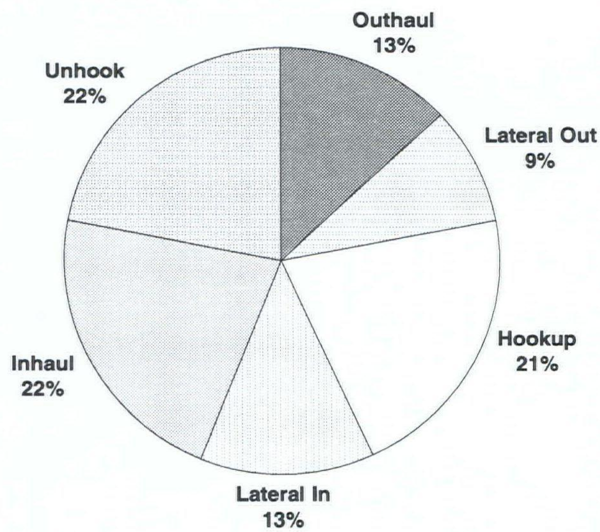

Figure 11. Cycle time distribution: multi-span yarding.

Single-span yarding:

[1] $CycleTime = 2.76140 + 0.00449 \cdot SlopeDist + 0.03750 \cdot LatDist$

$n = 472$ $R^2 = 49\%$ $SEE = 0.31$

Ranges for which the equation is applicable:

- SlopeDist: 10–350 m
- LatDist: 0–50 m

Multi-span yarding:

[2] CycleTime = 2.43108 + 0.00910•SlopeDist + 0.02563•LatDist

n = 307 R^2 =86% SEE = 0.28

Ranges for which the equation is applicable:

- SlopeDist: 10–420 m
- LatDist: 0–50 m

where:

CycleTime = Total delay-free cycle time (min)

SlopeDist = Slope yarding distance (m)

LatDist = Lateral yarding distance (m)

R^2 = Coefficient of multiple determination

SEE = Standard error of the estimate

Based on these equations, Figures 12 and 13 present system productivity for single- and multi-span configurations, respectively, as a function of slope and lateral yarding distances, based on 8-hour shifts, including delays. The average log size (calculated from total piece counts and scaled volume) was 0.47 m^3 and average number of logs per turn was 3.4, yielding an estimated average turn size of 1.6 m^3.

Figures 12 and 13 show that as yarding distance increases, productivity decreases faster for multi-span than single-span yarding. Also, when multi-span yarding, the influence of lateral yarding distance decreases as slope yarding distance increases, because phases related to lateral yarding (lateral out, hookup, lateral in) take a smaller proportion of total cycle time, and outhaul and inhaul become more time-consuming.

Figure 14 compares estimated productivities for single- and multi-span yarding, for a typical average lateral yarding distance of 25 m. This graph shows that productivity is similar for both systems for short slope yarding distances. However, as slope yarding distance increases (up to the maximum distance feasible for single-span yarding), productivity is higher for single-span than for multi-span yarding.

Removal Levels

Based on measurement of the original cruise plots, the average removal level with respect to basal area was 33%. Comparing the actual volume harvested (9650 m^3) to the initial volume estimated for the stand (25 620 m^3) yields a removal level of 38% by volume. Because the volume to be removed was calculated using a larger sample of cruise plots than the one used to estimate basal area removal after harvesting, it is concluded that the actual intensity of the cut was 38%, which corresponds to the silvicultural prescription (target removal of 40%).

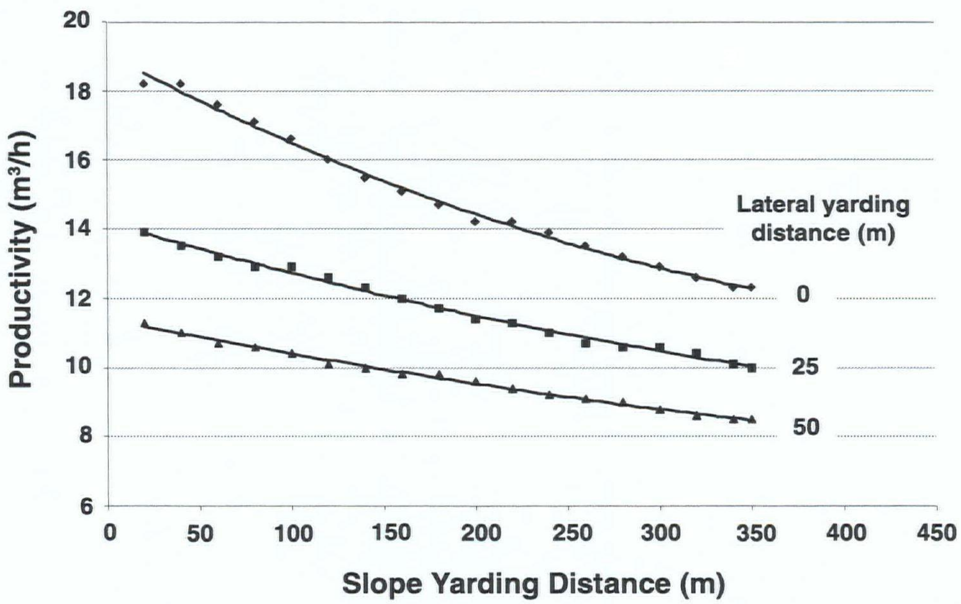

Figure 12. System productivity during scheduled yarding time: single-span yarding.

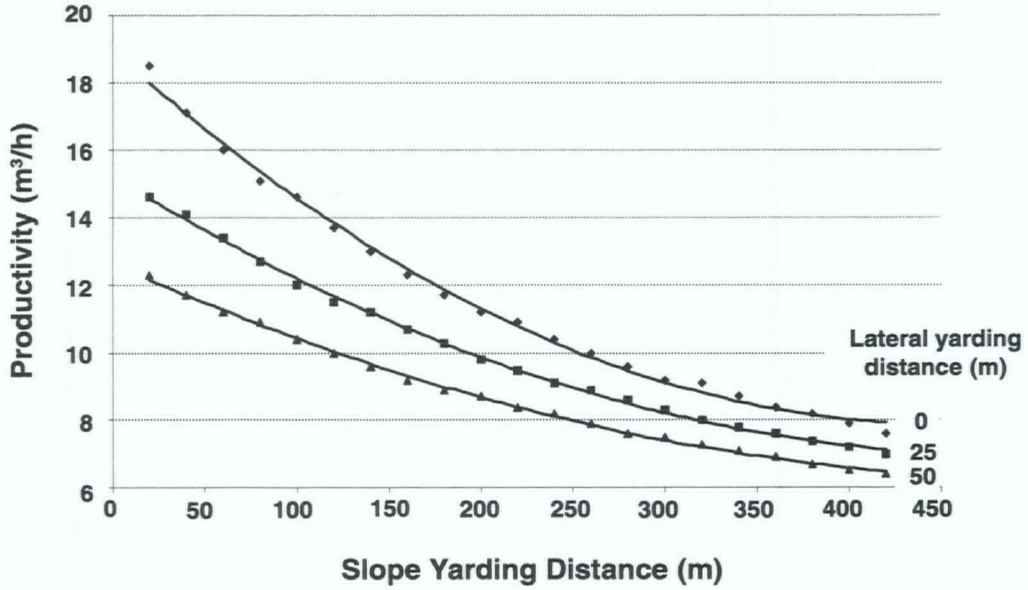

Figure 13. System productivity during scheduled yarding time: multi-span yarding.

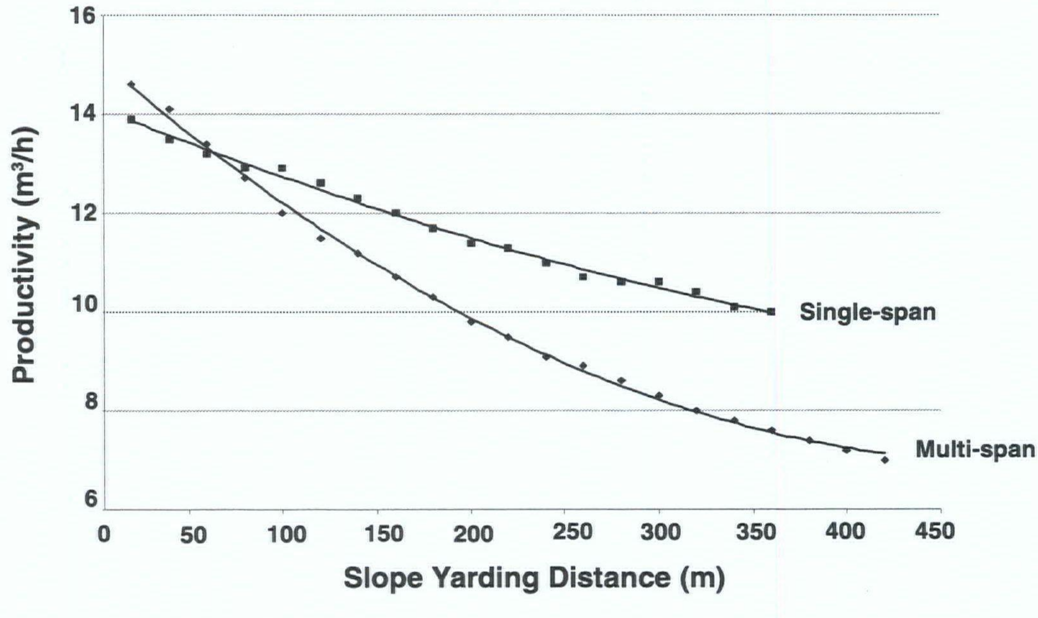

Figure 14. Comparison of single- and multi-span yarding productivities, for lateral yarding distance of 25 m.

Results for Site and Stand Damage

An attempt was made to evaluate stand damage after falling. For safety reasons this was rarely possible, but limited visual evaluation suggests that falling damage was negligible. Stand damage after yarding is summarized in Table 6.

The residual stand had a density of 500 trees/ha. Results showed that 12 trees/ha (2.4% of residual stand) had wounds that made them unacceptable as residual crop trees. When considering all wounds regardless of size, 27 trees/ha (5.4% of residual stand) were wounded. Most damage occurred by the hauling roads and close to yarding corridors.

A survey of soil surface conditions showed that this operation caused minimal soil disturbance. Only 1.5% of points analyzed were recorded as disturbed; of these, 1% represented disturbance in the organic layer only and 0.5% represented shallow disturbance into mineral soil. The survey found no potentially detrimental site disturbance in the cable-yarded area.

Table 6. Evaluation of Stand Damage

Cause of damage	Trees wounded under BCMOF criteria[a] (trees/ha)	(%)	All wounds considered: All wounds (trees/ha)	(%)	Scars >400 cm² (trees/ha)	(%)	Scars >900 cm² (trees/ha)	(%)
Engineering	1	0.2	1	0.2	-	-	-	-
Road building	1	0.2	1	0.2	-	-	-	-
Falling/yarding	10	2	25	5.0	8	1.6	1	0.2
Total	12	2.4	27	5.4	8	1.6	1	0.2

[a] According to BCMOF Tree Wounding and Decay Guidebook.

Visual Quality

The visual quality objective was fulfilled: harvesting is not visible from Highway 16. Figure 15 presents an aerial view of the cutblock, showing how the stand looked when harvesting was completed, and Figure 16 presents a view from inside the cutblock.

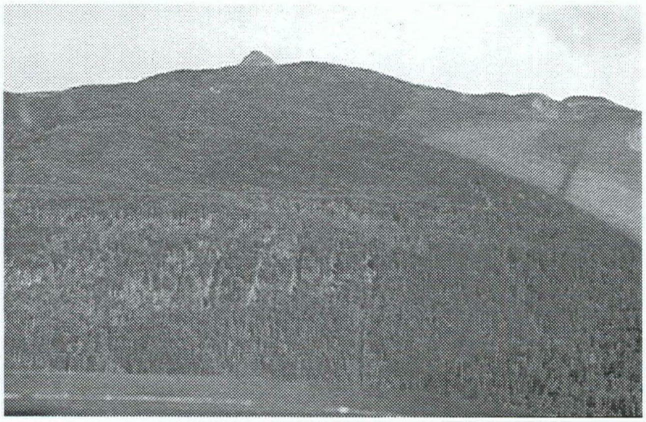

Figure 15. Aerial view of the cutblock.

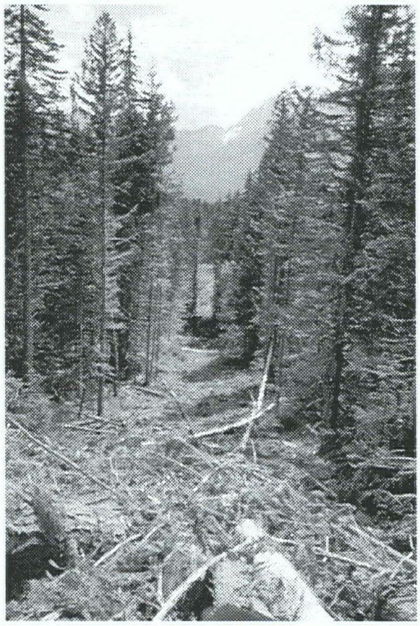

Figure 16. View along Corridor 25.

OTHER OBSERVATIONS

Based on observations while on site and frequent discussions with crew members, FERIC identified factors that could potentially affect the harvesting operation, as well as those that actually influenced the operation. These are described below along with recommendations on how to account for them in similar operations.

The relatively high yarding productivity and low incidence of damage to residual trees was attributed to the high quality of the falling phase. Directional falling had to be used for the entire cutblock and the faller was successful at consistently aligning stems for efficient yarding. The faller also marked corridor edges and then selected and cut the trees between corridors, in accordance with the Silviculture Prescription. Because of the confined space, the faller described falling in the corridor as being as difficult as falling right-of-way. The good quality of falling achieved in this cutblock was attributed to the faller's skill, and good communication between the faller, foreman, and forestry superintendent. Although trees could be premarked, faller selection is more efficient if the faller is well trained and experienced. When falling and yarding are done concurrently, a safe distance must be kept between workers; this requires planning the falling and yarding sequence of corridors to reduce idle time for the yarding phase.

With respect to the yarding phase, this trial reinforced the widely held view that careful planning is essential when laying out a setting where intermediate supports for the skyline are required. Good maps and numerous ground profiles are necessary to locate slope breaks where the intermediate supports will be needed. Experienced people are required to identify adequate intermediate support and backspar trees in terms of size and location, and to ensure there are adequate guyline stumps before roads, landings and yarding corridors are finalized. During the falling of the unit, good communication with the fallers is needed so that the required support trees remain standing.

Using intermediate supports requires more planning effort, implies greater risk due to the chance of a support failure, and produces slightly longer road change times. However, in the right circumstances, it may reduce the total cost of harvesting by:

- reducing the amount of road needed to log a cutblock
- improving skyline deflection on difficult yarding roads
- increasing turn payloads by dividing a long span into two or more shorter spans
- reducing the time required to yard a given setting by increasing average payloads
- offsetting the extra time required to rig an intermediate support, by reducing the number of machine moves and rig-ups on a given cutblock

In this study, the use of intermediate supports on six long yarding corridors improved skyline deflection and increased the area harvested from the cutblock's road system. Additional roads and landings would have been required to develop the same total area if only single-span yarding had been used. In addition to these features, it was observed that multi-span yarding provided additional control of the turn by limiting the lateral excursion of the skyline in the corridor, and thus reduced damage to the residual stand.

Multi-span yarding generally works best when the skyline is kept relatively tight (i.e., in the range of 5–8% deflection). This is especially important if there is a sharp break in the slope of the skyline path at the intermediate support, or if the intermediate support is relatively close to the yarder. If the skyline is not kept tight enough, excess slack accumulates in the lower span and the carriage tends to be pulled under the intermediate support during inhaul. The Mini-Maki II carriage used in this study was designed to minimize this tendency and therefore was a good choice for this operation.

However, for yarding distances longer than 300 m, the carriage had difficulty pulling slack. According to the technical specifications provided by the manufacturer, for the mainline used, the carriage should be able to pull slack at distances of greater than 700 m. Since the pads used on the carriage were almost new, the probable explanation for this problem was the overall wear of the carriage.

Although not encountered in this study, in general when performing partial cuts, some downtime could be expected because of wind. This can happen because it is hazardous for crews to work under standing trees that may have broken branches caught in their crowns.

One of the most important problems in harvest design is optimal spacing of haul roads, landings and, in partial cuts, yarding corridors. Important contributions to solving this problem were made by Matthews (1942) and Peters (1978), who attempted to develop a generalized solution. Sessions and Li (1987) presented the principles of optimizing road and landing spacing by using computer programs. With respect to spacing of yarding corridors, McNeel and Young (1994), Rutherford (1996) and Howard et al. (1996) have developed models specific to stands and sites in British Columbia, which predict optimal spacing from measurable stand and machine characteristics. Although this knowledge exists, it was not used in this trial to optimize corridor spacing, and in general is not considered when designing cable partial cuts. Forest engineers may not be aware of the existence of these models, or the models may not be presented in ways that are easy to apply even if the supporting research was performed to a high academic standard. Finally, in this particular trial, the spacing of yarding corridors was probably influenced more by the need to meet the visual, recreational, silvicultural and economic objectives for the site than to optimize yarding productivity. Cost savings might have been obtained by spacing skyline corridors according to these models, but these benefits would have to be weighed against the impacts of such changes on other management objectives.

At the beginning of the operation, the loader had to travel long distances between landings and different decks of logs to be loaded. In the second part of the cutblock, landings and piles were close and the work available was insufficient for the loader's capacity. Overall, the loader was under-utilized in this operation and could have handled a larger volume. However, it was a necessary component of the system and had to be available during the yarding operation.

CONCLUSIONS

In the summer and fall of 1997, FERIC monitored a partial cut in the ICH biogeoclimatic zone, near Kitwanga, B.C. Partial cutting was prescribed for the study site to address visual, recreational and silvicultural objectives.

The cutblock was manually felled and yarded with a Skylead C40 16000 yarder. The yarding pattern consisted of parallel 10-m-wide yarding corridors, spaced approximately 50 m apart and oriented perpendicular to the contours. Yarding corridors ranged from 40 to 420 m in length and required rigging both in single- and multi-span configurations. The removal level specified in the Silviculture Prescription was 40% of basal area; the actual reduction achieved was 38%. Although the crew was not experienced in partial cutting, the members were motivated and interested in obtaining new skills. Good supervision and communication, and good operating conditions also contributed to a successful operation.

Falling productivity was 99 m^3/shift and yarding productivity was 102 m^3/shift. The total cost for falling, yarding, processing and loading was $32.95/$m^3$. The engineering cost was estimated at $3.23/$m^3$, for a total cost of $36.18/$m^3$. Productivity functions were developed for the yarder, in both configurations, and a procedure for extrapolating results obtained in this study for other partial cuts was developed.

Operationally, falling is the most critical phase because the placement of stems directly affects yarding productivity and leave-tree damage. Overall, this study confirmed that it is essential to have a logging plan that considers all factors including backspar and landing locations, falling pattern and direction, location and loadpath analysis for yarding corridors, and other natural resource values. During cutblock design, the size, strength, vigour and species of backspars and tailhold trees must be considered. Clearly defined silvicultural objectives for locating skyline corridors and lateral rows are necessary to minimize the impact of harvesting on stand structure while maximizing economic returns.

Post-harvest survey showed that 5.4% of the residual stand was damaged by logging, and the impact of the operation on the site was negligible. Visual impact of the harvest was evaluated as well; the block was not visible from the highway. Narrow yarding corridors combined with an all-aged selection harvest meant canopy textures blended and the forest cover was maintained.

As this study demonstrated, multi-span yarding has several advantages, and in the right circumstances it may overcome many environmental and physical constraints to logging and achieve acceptable harvest costs.

In general, for alternative silvicultural systems, the overall cost (harvesting and regeneration) may be lowered if free-to-grow standards can be met earlier and at less cost; however, the loss of the residual stand volume, additional supervision requirements, and higher engineering costs must also be included in the equation. Long-term assessment of windthrow occurrence and regeneration success will answer some of the remaining questions about the applicability of this silvicultural system in the ICH biogeoclimatic zone.

RECOMMENDATIONS

Effective engineering (layout and load path analysis) is critical to ensure good yarding performance with cable systems. During the study, Corridor 51 had to be abandoned because the intermediate support tree was unsuitable for the expected loading. Consequently, lateral yarding distance on Corridors 50 and 52 had to be extended, adversely affecting yarder productivity. It is recommended that field engineers have adequate training in the selection and marking of intermediate support trees for multi-span cable systems.

As falling in partial cutting operations can present more risk of hangups and demand more skill in stem placement, it is recommended that fallers should:

- be well experienced with clearcutting before being exposed to partial cutting
- receive additional training on the principles of partial cutting with emphasis on silvicultural prescriptions, prevention of hangups and residual stand damage, and on the implications of good stem alignment for the safety and productivity of the subsequent yarding phase

To minimize yarding delays and residual stand damage, good carriage control when passing intermediate supports and precise carriage positioning when initiating lateral yarding are critical. Therefore, the rigging crew must have the ability and equipment to communicate effectively.

Effective utilization of the loader during the operation is important to ensure that the landing is clear and safe, and that trucks are loaded with minimum delay.

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Appendix I

Cycle Element Definitions

Outhaul:	Carriage travels along the skyline, from the landing to the hookup area.
Lateral out:	Pulling the machine's mainline laterally, from the carriage to the logs.
Hookup:	Setting chokers on the logs.
Lateral in:	Yarding the logs laterally, until the logs are suspended under the skyline carriage.
Inhaul:	Carriage and logs travel along the skyline to the landing.
Unhook:	Unhooking chokers at the landing.

Appendix II

Equipment Costs [a]

	Skylead C40 16000 yarder & skidder	Mini-Maki II carriage	Caterpillar EL 300 backspar (used)	Hitachi EX 270 LL log loader	Processor (tracked) with stroke delimber
OWNERSHIP COSTS					
Total purchase price (P) $	332 000	49 950	45 000	410 000	400 000
Expected life (Y) y	10	5	5	5	5
Expected life (H) h	16 000	8 000	7 200	10 000	10 000
Scheduled hours/year (h)=(H/Y) h	1 600	1 600	1 440	2 000	2 000
Salvage value as % of P (s) %	20	20	30	30	20
Interest rate (Int) %	10	10	10	10	10
Insurance rate (Ins) %	3	3	3	3	3
Salvage value (S)=((P•s)/100) $	66 400	9 990	13 500	123 000	80 000
Average investment (AVI)=((P+S)/2) $	199 200	29 970	29 250	266 500	240 000
Loss in resale value ((P-S)/H) $/h	16.60	5.00	4.38	28.70	32.00
Interest ((Int•AVI)/h) $/h	12.45	1.87	2.03	13.33	12.00
Insurance ((Ins•AVI)/h) $/h	3.74	0.56	0.61	4.00	3.60
Total ownership costs (OW) $/h	32.79	7.43	7.02	46.03	47.60
OPERATING COSTS					
Wire rope (wc) $	15 100	-	-	-	-
Wire rope life (wh) h	1 600	-	-	-	-
Rigging and radio (rc)	13 800	-	-	-	-
Rigging and radio life (rh) h	2 400	-	-	-	-
Fuel consumption (F) L/h	4	1	10	32	25
Fuel (fc) $/L	0.40	0.40	0.40	0.40	0.40
Lube and oil as % of fuel (fp) %	10	-	10	10	10
Track and undercarriage replacement (Tc) $	-	-	-	8 000	25 000
Track and undercarriage life (Th)	-	-	-	10 000	10 000
Annual repair & maintenance (Rp) $	12 000	3 500	5 000	32 800	64 000
Shift length (sl) h	8.7	8.7	8.7	8.7	8.7
Wire rope (wc/wh) $/h	9.44	-	-	-	-
Rigging and radio (rc/rh) $/h	5.75	-	-	-	-
Fuel (F•fc) $/h	1.60	0.40	4.00	12.80	10.00
Lube and oil ((fp/100)•(F•fc)) $/h	0.16	-	0.40	1.28	1.00
Repair and maintenance (Rp/h) $/h	7.50	2.19	3.47	16.40	32.00
Total operating costs (OP) $/h	24.45	2.59	7.87	30.48	43.00
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	57.24	10.02	14.89	76.51	90.60

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit and overhead and are not the actual costs for the contractor or the company studied.

Labour Costs

Description [a]	Hourly rate [b] ($)	Shift length [c] (h)	Shifts (no.)	Cost ($)	Cost ($/m³)[d]
Falling					
Fallers	52.31	7.5	84	32 955	3.42
Total falling	-	-	-	32 955	3.42
Yarding					
Yarding engineer	33.94	8.7	87	25 689	2.66
Hook and rig	34.86	8.7	87	26 386	2.73
Chaser	29.88	8.7	87	22 616	2.34
Chokersetter	29.59	8.7	43	11 070	1.15
Total yarding	-	-	-	85 761	8.89
Loading					
Loader operator	33.01	8.7	69	19 816	2.05
Total loading	-	-	-	19 816	2.05
Processing					
Processor operator	33.13	8.7	71	20 464	2.12
Total processing	-	-	-	20 464	2.12
Total labour cost	-	-	-	158 995	16.48

[a] The crew often performed tasks not described by their job titles. However, the rates did not change according to the task.
[b] Hourly rates are based on June 15, 1997 IWA rates, with 38% for fringe benefits and IWA standard prorated overtime allowance.
[c] Shift length excludes lunch.
[d] Based on a harvested volume of 9650 m^3.

Harvesting Costs

Description	Shifts (no.)	Shift length (SMH)	Hourly rate ($/SMH)	Cost ($)	Cost ($/m^3)
Falling					
Labour	84	7.5	52.31	32 955	3.42
Saw allowance [a]	84	-	-	2 268	0.24
Total falling	-	-	-	35 223	3.66
Yarding					
Labour [b]	76	8.7	129.70	85 761	8.89
Skylead C40 16000 yarder	87	8.7	57.24	43 325	4.49
Mini-Maki II carriage	87	8.7	10.02	7 584	0.79
Caterpillar EL 300 (backspar)	29	8.7	14.89	3 757	0.39
Total yarding	-	-	-	140 427	14.56
Loading					
Labour	69	8.7	33.01	19 816	2.05
Hitachi EX 270 LL log loader	69	8.7	76.51	45 929	4.76
Total loading	-	-	-	65 745	6.81
Processing					
Labour	71	8.7	33.13	20 464	2.12
Pierce processor	71	8.7	90.60	55 964	5.80
Total processing	-	-	-	76 428	7.92
Total labour cost	-	-	-	158 995	16.48
Total machine cost	-	-	-	158 827	16.47
Total harvesting cost	-	-	-	317 822	32.95

[a] Saw allowance is based on $27/shift.
[b] Based on three people working 87 shifts and one working 43 shifts.

Appendix III

Procedure for Using Results Obtained in this Study to Calculate Yarding Productivity and Cost for Other Partial Cutting Operations

The productivity equations developed in this paper are specific to the block studied. However, with appropriate caution, these equations can be used as a guide to estimate productivities for other yarding operations in similar site and stand conditions. The steps to be taken are presented below:

1. Choose the appropriate productivity equation, i.e., single- or multi-span yarding. If both methods are to be used, areas for each method should be calculated and each function used for its respective area.

2. Define the stand and site variables:

   - average external yarding distance

   - average lateral yarding distance

   - average number of logs per turn

   - average volume per log

3. Compute the mean time per turn (minutes).

4. Compute theoretical productivity per hour, by converting turn time to hours and multiplying by the volume per turn.

5. Compute actual productivity by adjusting for in-cycle delays.

6. Calculate theoretical productivity per shift by multiplying the value obtained at Step 5 by shift length.

7. Calculate actual productivity per shift by applying coefficients for yarder availability and utilization.

Based on these values and on the machine cost, the time necessary for the yarder to harvest the site and the cost of the operation can be estimated.

Care should be exercised not to use the productivity equations outside the ranges for which they were developed, and when choosing the various coefficients (proportion of in-cycle delays, yarder availability and utilization) required by this procedure.

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