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FACTORS AFFECTING PRODUCTIVITY OF SKYLINE YARDING SYSTEMS: RESULTS OF SIX CASE STUDIES IN NORTHWESTERN BRITISH COLUMBIA

Brian Boswell, R.P.F.

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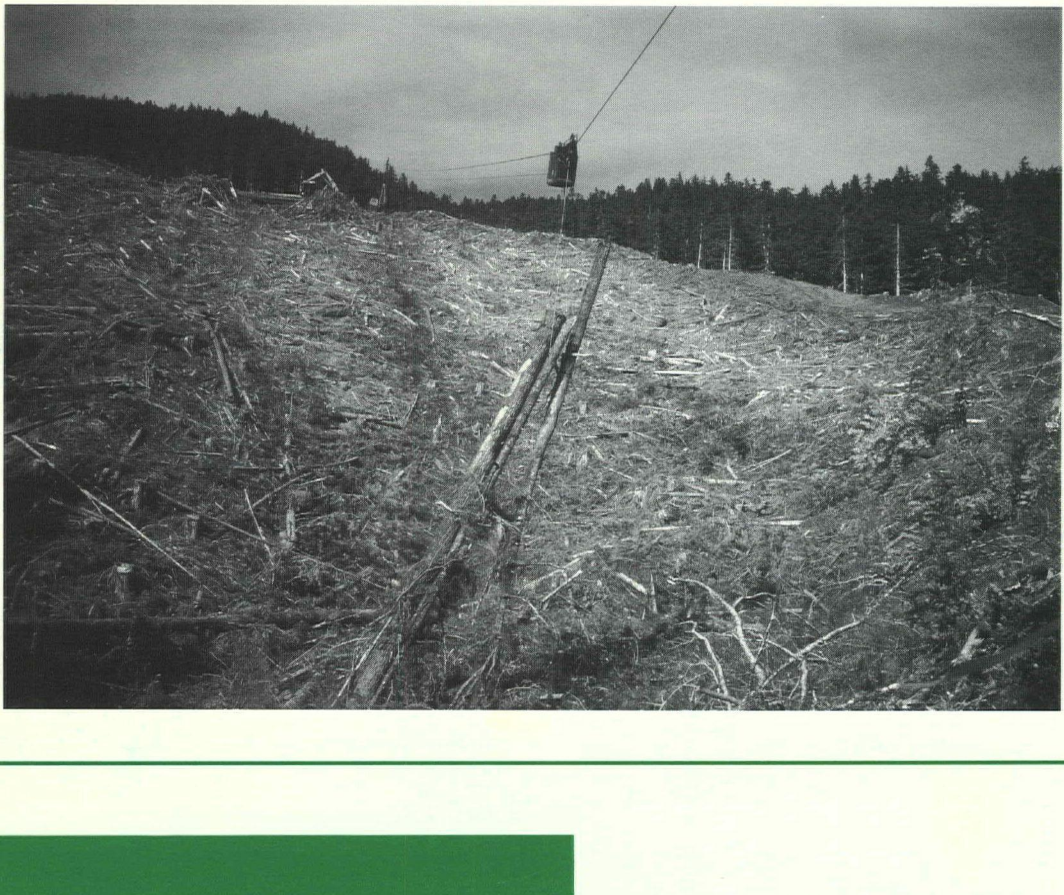

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Abstract

The Forest Engineering Research Institute of Canada (FERIC) conducted six case studies of long-distance skyline log-yarding systems operating near Terrace, British Columbia in 1995. Results include productivities, costs, and time distributions for yarding and loading logs, and regression models for yarding cycle time. Strategies to increase yarding productivity and reduce costs are suggested.

Author

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Disclaimer

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Summary

The Forest Engineering Research Institute of Canada (FERIC) conducted six case studies on long-distance skyline yarding systems operating near Terrace, British Columbia in 1995. The studies were conducted to investigate why skyline operators in B.C. are experiencing a wide range of productivies and costs. The study sites were located in the wet submaritime subzone of the Coastal Western Hemlock biogeoclimatic zone (CWHws).

Clearcut harvesting in old-growth western hemlock and amabilis fir was done with manual falling and cable-yarding systems using a number of different skyline yarders, carriages, and rigging configurations. Maximum yarding distances ranged from 455 to 750 m and logs were fully suspended when yarding over streams and buffer strips.

The study reports productivities, costs, time distributions, and delays for yarding and loading. Regression analysis was used to develop equations to predict delay-free cycle times. Cost and productivity results are compared with the results for highlead, grapple, and helicopter yarding systems from recent FERIC studies. Strategies to increase yarding productivity are suggested for layout, falling and yarding.

Long-distance skyline operations require good management to be efficient; otherwise, the consequences are low productivity and high costs relative to other cable systems. In this study, operators' productivities varied up to 61%. Results showed productivity to range from 91 to 147 m³/8-h shift with yarding and loading costs ranging from \$35 to \$52/m³. The contractor with the highest productivity and the lowest cost spent much less time in delays than the other contractors. This contractor used two separate teams of chokersetters on the skyline road whenever feasible and safe.

An effective way to improve productivity is to reduce delays. Managing the skyline system like a helicopter logging show in terms of high costs/min, and managing the total system to keep the carriage cycling back and forth as much as possible will improve system productivity.

Yarding with long-distance skyline systems is considerably more expensive than with highlead and grapple systems and areas for their application should be chosen carefully. They may be less expensive than heli-logging and should be considered in appropriate locations.

Sommaire

L'Institut canadien de recherches en génie forestier (FERIC) a réalisé six études de cas portant sur des systèmes de téléphérage à câble porteur longue-distance, en service près de Terrace, Colombie-Britannique en 1995. Les études avaient pour but d'examiner pourquoi, en Colombie-Britannique, les opérateurs de téléphériques à câble porteur ont des productivités et des coûts montrant une grande variation. Les aires d'étude étaient situées dans la sous-zone sous-maritime humide de la zone biogéoclimatique côtière de la pruche de l'Ouest (CWHws).

La récolte par coupe à blanc dans de vieux peuplements de pruche de l'Ouest et de sapin gracieux était effectuée par abattage manuel et téléphérage, en utilisant une bonne variété de téléphériques à câble porteur, de chariots et de configurations de câblage. Les distances maximales de téléphérage allaient de 455 à 750 m et les billes étaient entièrement suspendues quand elles passaient au-dessus des cours d'eau et des lisières boisées.

L'étude présente les productivités, les coûts, la ventilation des temps élémentaires et les temps morts pour le téléphérage et le chargement. Une analyse de régression a été utilisée pour développer des équations permettant de prévoir les temps du cycle sans temps morts. Les résultats de coût et de productivité sont comparés aux données obtenues lors de récentes études de FERIC pour les systèmes de téléphérage relevé, de téléphérage avec grappin et d'hélidébardage. Des stratégies visant à augmenter la productivité du téléphérage sont suggérées pour l'agencement du chantier, l'abattage et le téléphérage.

Pour être efficaces, les opérations utilisant un câble porteur sur de longues distances exigent une bonne organisation; autrement, on obtiendra une faible productivité et des coûts élevés par rapport à d'autres systèmes de téléphérage. Dans la présente étude, les niveaux de productivité des opérateurs variaient jusqu'à 61 %. Les résultats montrent que la productivité était de 91 à 147 m³/poste de 8 heures pour le téléphérage, et les coûts de chargement de 35 à 52 \$/m³. L'entrepreneur ayant la productivité la plus élevée et le coût le plus bas rencontrait beaucoup moins de temps morts que les autres. Cet entrepreneur utilisait deux équipes séparées d'élingueurs sur le trajet du câble porteur chaque fois que c'était réalisable et sécuritaire.

Un moyen efficace d'améliorer la productivité consiste à réduire les temps morts. La gestion du système à câble porteur comme une opération de débardage par hélicoptère en termes de coûts élevés/min, et la gestion du système total de manière à maintenir autant que

possible un va-et-vient continu du chariot amélioreront la productivité.

Les systèmes de téléphérage par câble porteur longue distance coûtent beaucoup plus cher que le téléphérage relevé et le téléphérage avec grappin, et il est nécessaire de choisir avec soin les aires où on y a recours. Ces systèmes peuvent être moins coûteux que l'hélidébardage et la possibilité de les utiliser devrait être envisagée aux endroits appropriés.

INTRODUCTION

While a skyline yarding system can be configured in various ways, generally speaking it consists of a cableway or skyline stretched between a spar tree or tower and an anchor stump or tailspar. The skyline serves as a track for the carriage which fully or partially suspends the logs while another cable called the mainline or skidding line pulls the carriage and logs along the skyline to the landing. Some skyline systems are referred to as long-distance skylines or longline systems because they are suspended across valleys, up to a distance of 1.5 km. No roads are required on one side of the span, and the logs can be fully suspended while they are being yarded over streams, regenerated forest stands, or other sensitive areas.

Since about the mid 1980s, the use of skyline yarding systems has increased in coastal British Columbia. Skyline systems can often harvest timber that is otherwise inaccessible because environmental concerns or high road-building costs prevent the use of ground-based, highlead, and grapple harvesting systems.

Skyline systems are more expensive and complex to operate than conventional yarding systems, and they require a higher level of skill to plan and operate safely and efficiently; skyline operators in B.C. have therefore experienced a wide range of productivities and costs. To investigate the reasons for this variability, the Forest Engineering Research Institute of Canada (FERIC) studied six different skyline operations working near Terrace, B.C., over a six-month period in 1995. The study had the following objectives:

- Determine average yarding and loading productivity and cost for each operation.
- Determine which factors influence productivity.
- Suggest strategies for improving productivity and for decreasing cost.

SITE AND STAND DESCRIPTIONS

The study blocks were located in the Kalum Forest District, in Skeena Cellulose Inc.'s (SCI) Tree Farm License, within a 70-km radius of Terrace, B.C.; haul distances were 50 to 80 km (Figure 1). Table 1 summarizes site and stand characteristics for the six blocks. The sites were in the wet submaritime subzone of the Coastal Western Hemlock (CWHws)

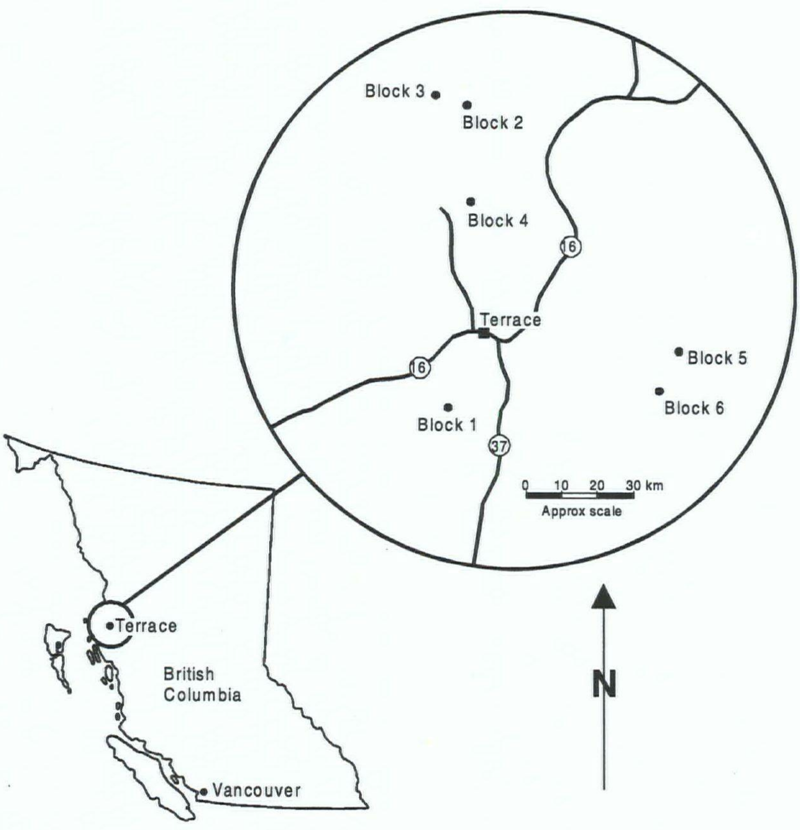

Figure 1. Location of study sites.

Table 1. Site and Stand Characteristics

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Harvested area (ha)	67.5	53.3	42.0	57.1	61.2	67.0
Harvested with skyline system (%)	90	100	70	32	88	78
Avg. ground slope (%)	63	71	65	58	55	57
Elevation (m)	600–900	600–850	500–700	350–850	600–900	500–600
Aspect	NE	NNW	SSE	W	E	W
Species composition						
Western hemlock (%)	36	53	52	79	87	61
Amabilis fir (%)	62	47	41	17	12	39
Spruce (%)	0	0	7	4	0	0
Other species (%) [a]	2	0	0	0	1	0
Avg. gross tree size (m^3)	3.1	2.6	3.2	1.4	2.4	2.9
Avg. dbh (cm)	52	51	56	42	50	53
Avg. total tree height (m)	42	38	39	30	35	40
Tree density (trees/ha)	326	321	254	539	373	378
Net volume (m^3/ha)	625	417	377	534	480	407
Decay, waste, breakage (%)	38	53	54	34	29	63

[a] Block 1 - Mountain hemlock; Block 5 - Western red cedar.

biogeoclimatic zone (Banner et al. 1993), and at elevations ranging from 350 to 950 m. All blocks had old-growth forest stands consisting predominantly of western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*). Slopes were very steep, exceeding 100% in some locations. The ground in Block 4 was very broken with many rock bluffs (Figure 2), while Blocks 3 and 6 both contained large streams with 100- to 150-m wide buffer strips of mature timber. Examples of ground profiles are shown in Appendix I.

HARVESTING SYSTEMS

Four contractors using four different yarders and four different cable configurations harvested the six blocks in the study (Table 2). For a detailed description of the cable systems and configurations, the reader is referred to *Cable Logging Systems* (Studier and Binkley 1974) or the *Cable Yarding Systems Handbook* (Tataryn 1993). Yarder and carriage specifications are shown in Appendix II. The silviculture system for all blocks was clearcut. Trees were handfelled, and most delimbing, topping, and bucking were performed at the stump (except in Block 4, see below). Prior to installing the skyline system, a grapple yarder or a highlead tower yarded the areas closest to the roads (except in Block 2).

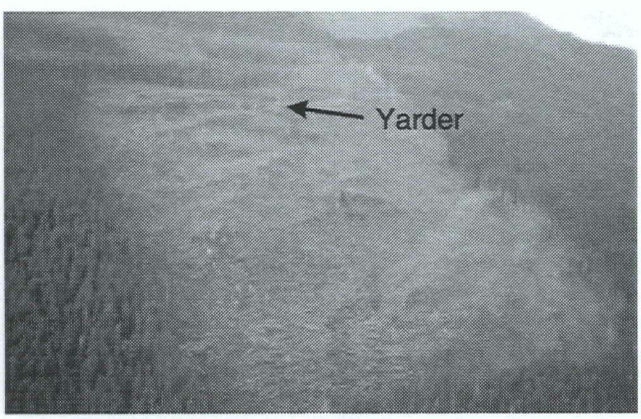

Figure 2. Aerial view of broken ground and rock bluffs in Block 4.

Block 1

A Thunderbird TMY-70 tower yarder and Eagle II and Eagle III (Figure 3) motorized slackpulling carriages yarded uphill, operating as a standing skyline[1] usually with gravity return. Unlike the other operations in the study which worked only one shift per day, this yarder operated two shifts per day during one-third of the study period, i.e., when daylight hours were long enough. The crew consisted of a yarder operator, a hooktender, one to two rigging slingers, one to two chokersetters, a chaser/ landing bucker, and a loader operator, for a total of six to eight people. During the double-shifting period, one hooktender was shared between the morning and the afternoon shifts, spending part of his time with each crew.

Chokers were preset using ring chokers and a T toggle connecting hook (Figure 4) on the skidding line. All the skyline anchors were stumps, and these were located

[1] In a standing skyline system, the skyline is not lowered and raised as part of the yarding cycle.

Table 2. Equipment Configurations and Operation Description

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Contractor number	1	2	2	3	4	4
Shifts/day (no.)	2	1	1	1	1	1
Bucking location	stump	stump	stump	landing	stump	stump
Yarder make & model	Thunderbird TMY-70	Thunderbird TY-90	Thunderbird TY-90	Madill 009	Washinton 78SL	Washington 78SL
Yarder type	skyline, tower	skyline, tower	skyline, tower	highlead, tower	skyline, swing	skyline, swing
Carriage make & model	Eagle II & III	Danebo shotgun	homemade	Eagle III	Eagle III	Eagle III
Carriage type	motorized slackpulling	shotgun	north bend	motorized slackpulling	motorized slackpulling	motorized slackpulling
Yarding direction	uphill	uphill	downhill	uphill	uphill	downhill
Cable configuration	standing skyline	live skyline	northbend	standing skyline	standing skyline	standing skyline
Haulback	no	no	yes	no	no	yes
Avg. crew size (no.) [a]	6.2	6.1	6.8	8.1	7.6	7.3
Chokers preset	yes	no	no	yes	yes	yes
Choker length (m) /dia (mm)	3.7/14	9.1/14	9.1/19	4.3/14	4.9/14	4.9/14
Chokersetting crews/road (no.)	1	1	1	2	1	1
Horizontal yarding dist. (m)	138–455	0–750	245–590	130–580	155–625	265–700
Horisontal dist. to anchor (m)	907	926	690	851	918	720
Cross-stream yarding	no	no	yes	no	no	yes
Skyline anchors	stumps	deadmen	rock bolts	rock bolts	stumps	stumps
Max. lateral yarding dist. (m)	80	0	65	40	80	75
Loader type	front-end	hydraulic	hydraulic	hydraulic	hydraulic	line
Loader application	dedicated	dedicated	dedicated	dedicated	dedicated	shared
Logs forwarded by loader	yes	yes	no	no	no	no

[a] Includes yarding and loading crews.

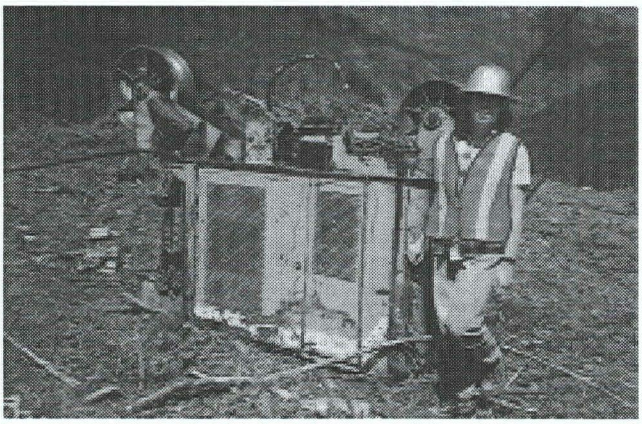

Figure 3. Eagle III motorized slackpulling carriage used in Blocks 1, 4, 5 and 6.

in standing timber on the other side of the valley, across a large creek. Maximum lateral yarding distance was 80 m. Occasionally the haulback line was hooked up to pull slack for turns with very wide lateral yarding.

A front-end loader was used for loading and landing duties, and was dedicated to the yarder. The loader forwarded logs 250 m to another landing for storage and loading because there was not enough room on the yarder landing for a front-end loader to perform these tasks. The loader operator was shared between the two shifts when the yarder was doubleshifting, starting with the morning crew and working 12 h/day until the middle of the afternoon shift. No trucks were loaded during the second half of the afternoon shift, i.e., after the loader operator went home; when required, the chaser operated the loader to clear the landing. The hooktender occasionally helped to buck and delimb logs at the landing.

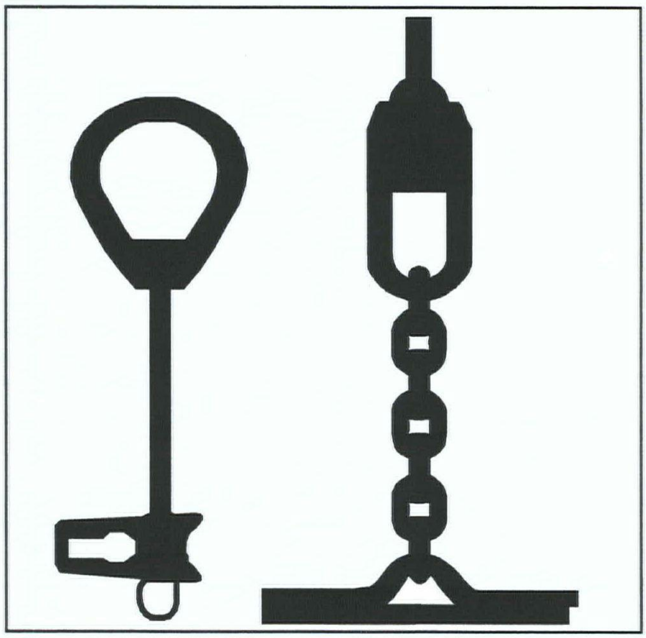

Figure 4. Ring choker and T toggle connecting hook, similar to those used in some of the study blocks.

Block 2

A Thunderbird TY-90 tower yarder and a Danebo shotgun carriage, operating as a live skyline[2] (a.k.a., a slackline) shotgun[3] system, yarded uphill. The crew consisted of a yarder operator, a hooktender, a rigging slinger, one to two chokersetters, a chaser/landing bucker, and a loader operator, for a total of six to seven people.

Chokers were not preset because the shotgun system used in Block 2 had limited lateral yarding capability. In order to increase the system's lateral yarding capabilities, a 9-m extension cable was attached to the carriage, to which the 9-m-long chokers were attached (Figure 5). Horizontal yarding distances were 0–750 m. The skyline system yarded the entire area from the road to the cutting boundary. Deadmen[4] were used as skyline anchors and were located in standing timber across a large creek. In this block, the road extended to near the cutting boundary. A hydraulic log loader was dedicated to this yarder and forwarded logs from the landing to a loading site 30 m away because the landing was too steep for logging trucks.

Figure 5. Shotgun carriage with a 9-m extension line attached to the chokers, Block 2.

Block 3

A Thunderbird TY-90 yarder, configured as a north bend[5] system with a home-made north bend carriage (Appendix III), yarded downhill. The crew consisted of a yarder operator, a hooktender, a rigging slinger, one to two chokersetters, a chaser/landing bucker, and a loader operator for a total of six to seven people.

The north bend system achieved lateral yarding by sideblocking,[6] therefore preset chokers were not used. The cutblock spanned a valley with a major stream and buffer strip (Figure 6), and cross-stream yarding was required. Logs were fully suspended as they were yarded over the creek and buffer strip. Rock bolts were used for the skyline anchors. A hydraulic loader was dedicated to this yarder.

Figure 6. Sideblocking with the north bend system in Block 3. Logs were fully suspended over the creek and buffer strip shown in the centre of the photo.

Block 4

A modified Madill 009 highlead tower yarder and an Eagle III carriage were used to yard uphill with the cables configured as a standing skyline, shotgun system. Yarder modifications included installing three buckle guylines and a shotgun fairlead[7] (Figure 7) on the tower, and changing the mainline water-cooled disk brake to a band brake. Trees in this block were handfelled and most of the delimbing and topping was

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[2] When operating as a live skyline system, the skyline is raised and lowered each turn.

[3] A shotgun system uses gravity, rather than a haulback line, to return the carriage to the woods.

[4] A deadman is an artificial anchor made by burying a large log or other object when suitable anchor stumps are unavailable.

[5] North bend is a standing skyline system where the skidding line runs from the yarder through a fall block and is attached to a carriage or rider block on the skyline. The haulback line and chokers are attached to the fall block. Refer to Studier and Binkley (1974) or Tataryn (1993) for more information.

[6] Sideblocking refers to locating a haulback block beyond the normal width of the skyline road in order to reach logs outside the carriage's usual line of travel.

[7] A shotgun fairlead is a fairlead added to a highlead tower below the mainline fairlead, thus allowing the haulback line to be used as the skidding line and the mainline to be used as the skyline when shotgunning.

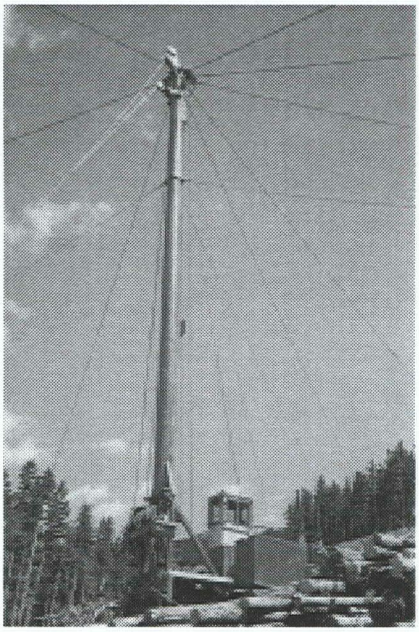

Figure 7. Modified Madill 009 highlead yarder with buckle guylines and shotgun fairlead, Block 4.

Figure 8. Four rock bolts, equalizer shoes, and rigging for a skyline anchor in Block 4.

done at the stump. Unlike the other blocks, most of the bucking was performed at the landing in order to deal efficiently with the smaller trees on this site. The crew consisted of a yarder operator, one to two hooktenders, one to two rigging slingers, one to two chokersetters, a chaser/landing bucker, a second loader,[8] and a loader operator for a total of seven to ten people.

Chokers were preset using ring chokers and a T toggle connecting hook on the skidding line. This crew was organized differently than the others, with two teams of two people and each team setting chokers at different locations on the skyline road. The carriage alternated between the two crews when picking up turns. The skyline anchors (rock bolts) (Figure 8) were located in the standing timber on the other side of the valley, across a large creek. A hydraulic loader was dedicated to this yarder.

Block 5

A Washington 78SL swing yarder and an Eagle III carriage yarded uphill with the cables configured in a standing skyline, gravity-return (shotgun) system. The swing yarder had been modified with the addition of a 76-cm cab riser with a hydraulic tilt and the replacement of the standard engine (a 671 GMC) with a 692T turbo GMC. The crew consisted of a yarder operator, a hooktender, one to two rigging slingers, one to two chokersetters, a chaser, a second loader, and a loader operator, for a total of seven to nine people.

Preset ring chokers were used with a T hook on the skidding line. The skyline anchors—all stumps—were located in standing timber on the other side of the valley, across a large creek. Maximum lateral yarding distance was 80 m. Occasionally the haulback line was hooked up to pull slack for turns with very wide lateral yarding. A hydraulic loader was dedicated to this yarder.

Block 6

A Washington 78SL swing yarder (Figure 9) and an Eagle III carriage yarded downhill with the cables configured as a standing skyline with a haulback line. The crew consisted of a yarder operator, a hooktender, one to two rigging slingers, one chokersetter, a chaser, a second loader, and a loader operator, for a total of seven to eight people.

Chokers were preset using ring chokers and a T hook on the skidding line. The yarder was positioned on a spur road above the landing that was located on a lower road (Appendix I). The cutblock spanned a valley with a major stream and buffer strip, therefore cross-stream yarding was required. Logs were fully suspended while they were yarded over the creek and buffer strip. All skyline anchors were stumps. A line loader was used and was shared with another yarding machine during the first third of the study period.

[8] A second loader is a worker who bucks logs and assists the loader operator in loading logging trucks. He is affiliated with the loader rather than the yarder.

Figure 9. Washington 78SL swing yarder with 76-cm cab riser, used in Blocks 5 and 6.

STUDY METHODS

Servis recorders mounted on the yarders and loaders recorded scheduled machine hours (SMH), productive machine hours (PMH), and delays greater than 15 min. Machine operators recorded piece and turn counts, delay details, road changes, weather conditions, and comments on daily report forms. Skeena Cellulose Inc. provided scale information which was used to determine average piece sizes and overall productivities for each block. Statistical analysis was used to determine the influence of shift type (one-way analysis of variance (ANOVA)) and fog (*t*-test) on yarding productivities in Block 1.

Assumptions used in cost calculations are shown in Appendix IV and cost calculations for the rock bolt anchors are shown in Appendix V. Hourly equipment ownership and operating costs were determined based on FERIC's standard costing methodology (Appendix VI). To calculate unit yarding and loading costs for each block, hourly equipment costs were applied to the average yarding productivities determined in the shift level studies.

Detailed timing of yarding was conducted on each block and the data were used to determine average total cycle times and average yarding cycle element times, time distributions, and delays ≦15 min. Delay-free cycle times were estimated at standardized yarding distances by using average outhaul and inhaul speeds and the average times for other cycle elements. Multiple-regression analysis was performed to develop predictive equations for delay-free cycle times for each block. Detailed timing of the loaders was conducted on Blocks 1, 2, 4, and 5, and the data were used to determine loader time distributions.

RESULTS

Productivity and Cost

Productivity ranged from 91 to 147 m³/8-h shift (Table 3), including all moves, road changes, and delays, for an overall yarding and loading cost of \$51.72 to \$34.51/m³ (Table 4). Productivity per PMH, excluding delays longer than 15 min, ranged from 13.1 to 19.4 m³. Productivity per yarding hour (YH), excluding all moves, road changes, and delays longer than 15 min, was 1.6 to 7 m³ higher for the slackpulling system blocks (Blocks 1, 4, 5, and 6) than for the non-slackpulling system blocks (Blocks 2 and 3). However, when road changes and delays are taken into account, productivity per SMH for the shotgun system block (Block 2) was similar to that of the least productive slackpulling system block (Block 6). It should also be noted that Blocks 2 and 6 had the longest yarding distances, at 750 and 700 m respectively. With the exception of Block 1, productivity generally increased and cost decreased as net volume/ha increased. However, productivity decreased and costs increased as tree size increased and density (trees/ha) decreased. Therefore, it appears that volume/ha and other factors had a much greater influence on productivity than tree size.

Operations in Block 4 achieved the highest productivity and the lowest cost. Compared to the average productivity on the other blocks, the operation on Block 4 was 44% more productive based on scheduled time, and 31% more productive based on productive time.

For Block 1, productivities for the morning, afternoon, and regular shifts were 20.3, 20.1, and 19.1 m³/YH, respectively. These differences were not statistically significant.[9]

The effect of fog on yarding in Block 1 was investigated by comparing productivities on 27 days with fog to productivities on 29 days with no fog and with similar yarding distances. The average yarding productivity was 20.4 m³/YH on days with no fog, and 18.5 m³/YH on days with some fog. Although these differences were not statistically significant,[9] the contractors believed fog was an important influence on productivity and costs.

Because fog reduces visibility, the licensee and contractors also raised concerns about worker safety including the potential inability to conduct an aerial evacuation of an injured worker. Workers' Compensation

[9] ANOVA single factor test, 0.05 level of significance.

Table 3. Yarder Productivity

	Block 1, TMY-70	Block 2, TY-90	Block 3, TY-90	Block 4, Madill 009	Block 5, Wash. 78SL	Block 6, Wash. 78SL	All [a]
Sample size (8-h shifts)	134	61	36	49	53	47	380
(m^3)	14 747	6194	3302	7249	5664	4727	41 883
Avg. shift length (h)	8.3	8.8	8.3	8.3	8.7	8.7	8.5
Piece size (m^3)	1.1	1.2	0.8 [b]	0.7	0.9	1.2	1.0
Turn size (pieces)	3.1	3.0	4.2 [b]	4.7	3.5	2.8	3.4
Turn size (m^3)	3.4	3.6	3.4	3.3	3.2	3.4	3.4
Time/turn (min)	10.6	11.4	10.9	7.9	9.8	10.2	10.2
Productivity [c]							
m^3/SMH	13.8	12.6	11.4	18.4	13.3	12.7	13.8
m^3/PMH	16.2	15.1	13.1	19.4	14.3	15.4	15.8
m^3/YH	19.2	17.6	17.6	24.6	19.6	19.4	19.6
m^3/8-h shift	110	101	91	147	107	101	110

[a] Weighted by sample size in shifts.
[b] Based on only 3 days of data.
[c] SMH = scheduled machine hour.
PMH = productive machine hour (excludes delays >15 min).
YH = yarding hour (excludes delays >15 min, set-up and dismantle, and road change times).

Table 4. Yarding and Loading Cost Summary

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	All
Yarder (\$/m^3)	27.03	34.44	38.28	24.54	31.58	30.60	29.60
Carriage (\$/m^3)	1.53	incl. w/yarder cost		1.21	1.67	1.76	1.17
Loader (\$/m^3)	7.03	9.37	10.41	6.45	8.89	9.36	8.06
Helicopter and fuel (\$/m^3)	0.15	0.00	0.00	0.44	0.89	0.57	0.31
Line horse (\$/m^3)	0.01	0.00	0.00	0.38	0.00	0.11	0.08
Rock bolts and installation (\$/m^3)	0.58	1.28	2.20	0.64	0.70	0.70	0.85
Power saw and fuel (\$/m^3)	0.68	0.74	0.82	0.85	1.17	1.23	0.86
Total (\$/m^3)	37.01	45.82	51.71	34.51	44.90	44.33	40.93

Board of British Columbia (WCB) regulation 26.17 states: "When weather conditions create hazards to workers, additional precautions must be taken as necessary for the safe conduct of the work" (WCB 1997). An interpretation of this regulation in regard to fog and rigging crews states: "Work can proceed in thick fog provided: 1. Radio or radio whistle (as required) communication is used; i.e., hand signals are not used. 2) The rigging crew can, from a safe location, see to spot the rigging and watch the turn move away; 3) No one in the settings or landings is endangered by potential run-away logs or material, i.e., run-aways will be seen soon enough to allow evasive action. 4) The yarder engineer can see to land the turn and a short distance behind the pile. 5) All equipment and log movement within the landing is visible to those who might be affected" (White 1999).

Time Distributions

This section discusses the distributions of SMH and PMH for the yarders and loaders in the study.

Scheduled machine hours for yarders

Yarding logs accounted for 65–75% of the yarders' scheduled time (Figure 10). Road changes averaged 6% with little difference between the blocks. "Walk to and from the site" took an average of 3% of scheduled time and was as high as 6% for Block 5. This activity is defined as the non-yarding time at the beginning of the shift when the rigging crew was walking from the road to the first turn, and at the end of the shift when the crew was walking from the last turn to the road. Block 4 reduced this non-productive time by working two crews on a skyline road whenever possible. Delays greater than

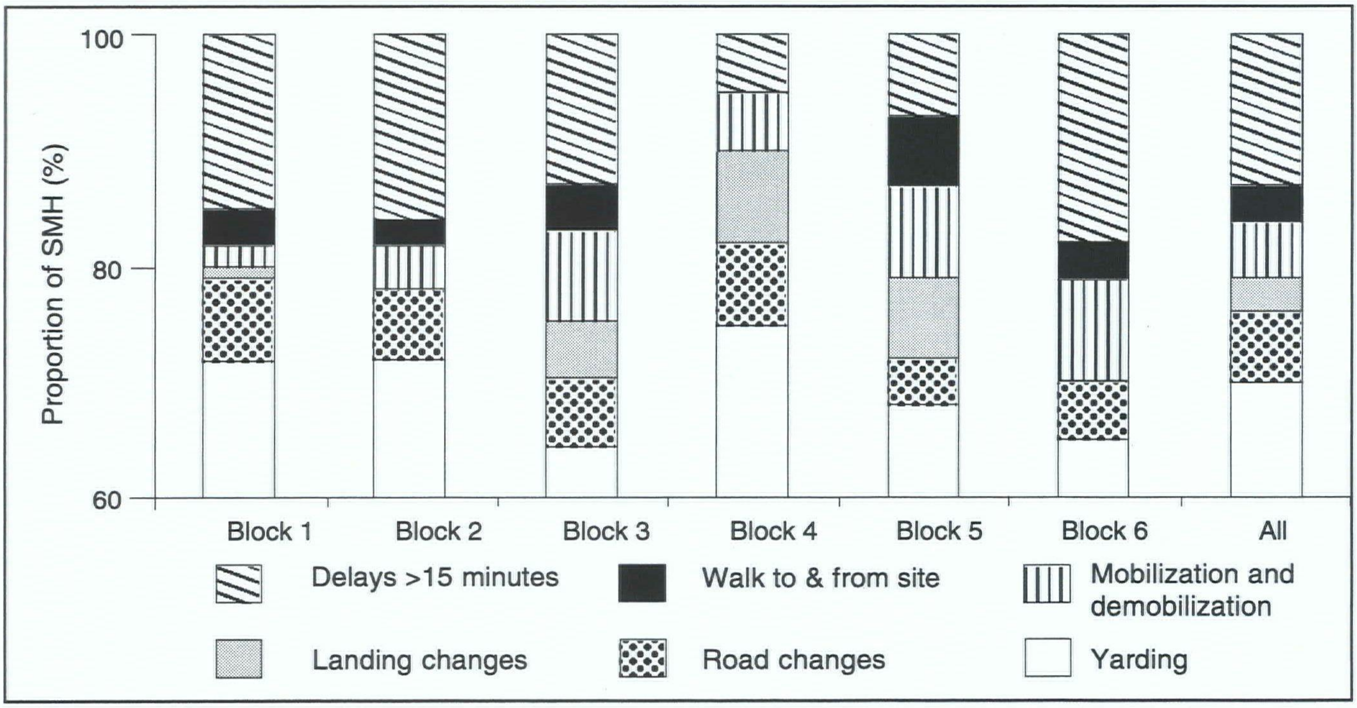

Figure 10. Time distribution for yarders.

15 min absorbed an average of 13% of all scheduled time ranging from a low of 5% for Block 4 to a high of 18% for Block 6. Table 5 shows the distribution of these delays. The two most time-consuming delay categories were "rigging" and "mechanical, carriage". A large portion of delays were classified as unknown because the machine operators did not always describe the delays on the daily report forms. All contractors using motorized carriages spent considerable time addressing carriage-related delays.

Road and landing change, mobilization and set-up, and dismantle and demobilization times are reported in Table 6. Road changes were considerably faster in the non-slackpulling system blocks, i.e., 2 to 3 h/change compared to 5 to 7 h/change for the slackpulling system blocks, but the proportion of scheduled time spent changing roads differed little between the systems (Figure 10). More road changes were required with the narrow lateral yarding capability of the non-slackpulling systems. Yarder mobilization and set-up time averaged 15.1 h, landing changes averaged 12.7 h, and dismantle and demobilization averaged 10.1 h. Occasionally, rigging activities such as splicing or upending lines[10] were done during set-ups or road changes and may be included in some of the longer times reported. An average of 776 m^3/road was yarded on the 54 skyline roads, with a low of 300 m^3/road in Block 3 and a high of 1134 m^3/road in Block 1. The blocks yarded with motorized slackpulling carriage systems had the greatest average skyline road widths and the highest volume yarded/road, as would be expected. However, the blocks with the highest volume yarded/road also had the highest volume/ha.

Scheduled machine hours for loaders

The log loaders in five blocks were studied in order to analyze their work activities. Shift-level Servis recorder data and operator forms showed that the loaders spent 71% of the time working, 24% idle, and 6% in delays (Figure 11). In Block 4, with the highest yarding productivity, the loader had only 1% delay time and worked 79% of the time.

Productive machine hours for loaders

Detailed timing of the loaders for 129 SMH in four blocks provided a more detailed distribution of loader activities (Table 7). Forwarding logs in Block 1 took 22% of the loader's time because the front-end loader had to move all logs to another landing to have enough room to load the logging trucks. In the other blocks, where hydraulic loaders were used, trucks could be loaded from the yarder landings, even though the landings were similar or smaller in size, resulting in only 2 to 8% of the loader time spent forwarding logs. However, the front-end loader in Block 1 spent less time sorting and decking logs and clearing logs from the landing than loaders in other blocks due to its higher travel speed and ability to grapple more logs at a time; therefore the Block 1 loader had an overall higher proportion of idle time.

[10] Upending a line involves reversing the ends of a line to equalize wear.

Table 5. Yarding Delays >15 min (from shift-level study)

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	All
Sample size (8-h shifts)	134	61	36	49	53	47	380
Time in delays >15 min (h)	162.1	79.4	38.6	20.6	29.4	65.7	395.8
Delays >15 min (no.)	129	40	25	20	29	31	274
Avg. time/delay (h)	1.3	2.0	1.5	1.0	1.0	2.1	1.4
Avg. delay time/shift (h)	1.2	1.3	1.1	0.4	0.6	1.4	1.0
Proportion of delays (%)							
Mechanical, carriage	25	0	2	26	0	37	18
Mechanical, yarder	8	9	9	4	29	0	8
Radio, yarder	1	7	0	12	2	0	2
Rigging	38	51	17	32	19	33	36
Preparation for road change	4	0	0	8	10	0	3
Wait for parts or mechanic	7	0	0	0	0	0	3
Injury	5	0	0	0	0	0	2
Unknown/other	12	33	72	18	40	30	28
Total	100	100	100	100	100	100	100

Examples of some of the longer delays are broken skyline, 20 h (Block 2); install new mainline, 9 h (Block 6); install new skyline, 7 h (Block 1); injury, 5 h (Block 1); upend the haulback, 4 h (Block 4); dropped carriage, 4 h (Block 6); splice haulback, 4 h, (Block 3); broken mainline, 2 h (Block 5).

Table 6. Skyline Road Change and Landing Change Times

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	All
Mobilization and set-up time (h)	15.0	16.0 [a]	19.5	8.0	16.0 [a]	16.0	15.1
Skyline road changes							
Road changes (no.)	11	11	8	4	4	4	42
Range of road change times (h)	1.6–10.8	1.2–5.3	0.2–5.9	5.1–10.0	1.8–9.0	4.0–7.2	0.2–10.8
Avg. road change time (h)	6.6	2.8	2.1	6.6	5.0	5.1	4.5
Landing changes							
Landing changes (no.)	1	0	2	2	1	0	6
Range of landing change times (h)	5.9	-	6.3–8.0	14.8–15.4	26.1	-	5.9–26.1
Avg. landing change times (h)	5.9	-	7.1	15.1	26.1	-	12.7
Demobilization and dismantle time (h)	8.0	3.3	2.5	13.3	17.5	16.0	10.1
Average volume yarded (m^3/road) [b]	1134	516	300	1036	944	945	776
Average skyline road width (m) [c]	57	17	23	65	42	53	40 [d]
Road change time (min/m^3)	0.35	0.33	0.42	0.38	0.32	0.32	0.34

[a] Estimated.
[b] Calculated as follows: m^3/block / roads/block. Roads/block equals 1 setup road + no. of road changes + number of landing changes.
[c] Calculated as follows: m^3/road / m^3/ha x 10 000 m^2/ha / avg. length yarded/road (estimated from map).
[d] Weighted by the number of roads.

The hydraulic loader used in Block 2 spent only 8% of its time forwarding logs, despite the operator's concerns about the landing layout and difficulties created by it. (Access to the landing was too steep for logging trucks so the loader forwarded the logs 30 m up the road for loading.) The time study showed that all the hydraulic loaders spent fairly similar proportions of time in each activity.

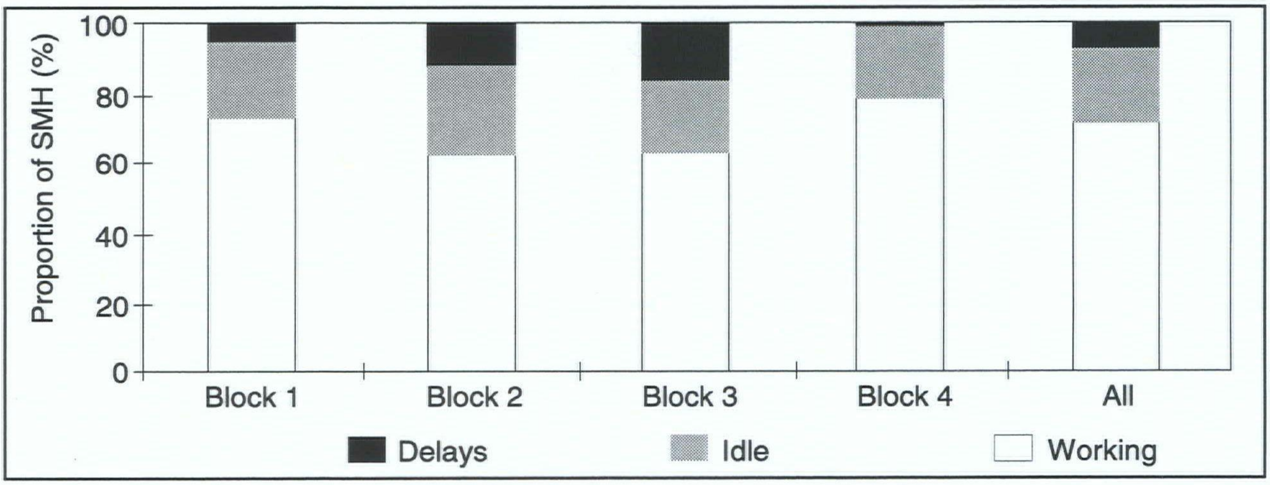

Figure 11. Time distribution for loaders (from shift level study) (no data for Blocks 5 and 6).

Table 7. Time Distribution for Loaders (from detailed timing study) [a]

	Block 1	Block 2	Block 4	Block 5	All
Sample size (SMH)	39	32	14	44	129
Proportion of time (%)					
Clearing landing area of logs	11	15	23	21	17
Waiting for chaser	1	1	1	2	1
Waiting for bucker	7	3	2	4	4
Sorting and decking logs	8	21	29	29	21
Forwarding logs	22	8	7	2	10
Loading trucks	14	12	11	12	13
Clearing debris	3	2	2	5	3
Idle	31	24	18	21	24
Other [b]	3	14	7	4	7
Total	100	100	100	100	100

[a] No data for Blocks 3 and 6.
[b] Includes machine maintenance and repairs, talking to supervisor, etc.

Productive machine hours for yarders - the yarding cycle

Table 8 shows the results from the detailed timing study. Average delay-free cycle times ranged from 6.06 min in Block 4 to 11.54 min in Block 3. The following observations from the detailed timing study compare and contrast the activities on the blocks and the harvesting systems.

Outhaul. Outhaul was slower when using a haulback and yarding downhill compared to using gravity return when yarding uphill. The TY-90 had an average outhaul speed of 675 m/min in Block 2, with gravity return, compared to 396 m/min in Block 3, with a haulback. The 78SL had an average outhaul speed of 522 m/min in Block 5 with gravity return, compared to only 393 m/min when using a haulback in Block 6.

Drop chokers. The distance that the chokers must be lowered to the ground with these long-distance skyline systems can be considerable; in this study the distance was over 180 m in some instances (Appendix I). As a result, an average of 9% of the cycle time was spent on this cycle element, i.e., almost the same amount of time as for outhaul. Maximum times for drop chokers were over 2 min/cycle for most blocks.

The north bend system used in Block 3 had the shortest average time at 0.25 min/turn. To drop the chokers, this system used both the power of the yarder pulling the haulback and the power of gravity by slacking the skyline and/or skidding line. The slackpulling carriage systems used in Blocks 1, 4, 5, and 6 relied on the small engine in the carriage to drop the chokers, which took an average time of 0.67 min/turn. In Block 2 the shotgun

Table 8. Yarding Detailed-Timing Summary

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	All	All (%)
Cycles (no.)	269	134	46	125	300	99	973	
Yarding cycle elements (min) [a]								
Outhaul	0.59	0.75	1.15	0.70	0.60	1.19	0.72	10
Drop chokers	0.87	0.57	0.25	0.72	0.55	0.41	0.63	9
Lateral-out [b]	1.28	0.00	1.02	0.84	1.17	0.49	0.92	12
Hookup	1.36	3.65	4.76	1.26	1.07	1.76	1.78	24
Lateral-in	1.04	0.44	1.20	0.75	1.00	0.93	0.90	12
Inhaul	1.04	3.14	1.59	0.94	1.03	1.32	1.37	18
Unhook	1.02	1.48	1.57	0.85	1.03	1.46	1.14	15
Total delay-free cycle time	7.20	10.03	11.54	6.06	6.45	7.56	7.46	100
Delay time/cycle (≦15 min)	0.74	0.88	0.68	0.22	0.53	1.02	0.66	9
Total cycle time including delays ≦15 min	7.94	10.91	12.22	6.28	6.98	8.58	8.12	109
Average outhaul speed (m/min)	554	675	396	453	522	393	508	-
Average inhaul speed (m/min)	314	161	286	337	304	355	267	-
Yarding study average parameters								
Slope yarding distance (m)	327	506	455	317	313	468	366	-
Lateral yarding distance (m)	20	-	37	17	21	8	17	-
Logs yarded/cycle (no.)	2.9	3.1	3.8	4.9	4.0	2.7	3.5	-
Volume/log (m^3) [c]	1.1	1.2	0.8	0.7	0.9	1.2	1.0	-
Volume yarded/cycle (m)	3.2	3.7	3.0	3.4	3.6	3.2	3.5	-
Standarized delay-free cycle time (min) [d]								
200-m slope yarding distance	6.57	7.68	10.00	5.45	5.86	6.12	6.51	-
400-m slope yarding distance	7.57	9.22	11.21	6.49	6.90	7.19	7.66	-
600-m slope yarding distnace	8.56	10.76	12.41	7.52	7.94	8.27	8.80	-

[a] Average time.
[b] Equals walk into turn in Block 3, see text.
[c] Based on shift-level data.
[d] Standarized using average outhaul and inhaul speeds and average time for other cycle elements.

system used gravity to drop the chokers by slacking the skyline; the drop time, at 0.57 min/turn, was similar to those blocks where the slackpulling system was used.

Lateral-out. No lateral-out time element was used in Block 2 because with the shotgun system, lateral yarding is limited to the length of the chokers.

When sideblocking in Block 3, lateral-out occurred simultaneously with dropping the chokers to the ground, and therefore was classified as part of drop chokers. The time spent by chokersetters to walk into the turn was classified as lateral-out.

Hookup. Hookup included walking to the turn (except Block 3), untangling the chokers (Blocks 2 and 3 only), hooking up the dropline and setting the chokers for the next turn (when the chokers were preset) or setting the chokers for the current turn (when the chokers were not preset), and getting in the clear.

Overall, hookup was the most time-consuming cycle element, averaging 1.78 min/turn or 24% of the cycle time.

The longest average hookup times occurred in the two blocks where chokers were not preset: Blocks 2 and 3 at 3.65 and 4.76 min/turn, respectively.

In Blocks 2 and 3 with the non-slackpulling systems and without the use of pre-set chokers, extra time was required to untangle chokers during hookup, consuming 1.13 and 0.35 min/turn in Blocks 2 and 3, respectively. Untangling the chokers rarely occurred on the other blocks; when it did occur, it was classified as a rigging delay.

Getting in the clear took extra time when using a haulback, for example, 1.33 min/turn for Block 3 with a haulback compared to 0.51 min/turn for Block 2 without a haulback, using the same machine and crew.

Hookup time for Block 6 was longer than for the other slackpulling system blocks. Snow was present during some of the timing period in Block 6 and it may have contributed to the longer times.

Lateral-in. Lateral-in included repositioning the carriage (in order to redirect the breakout forces in a safe direction), lateral-inhaul to the skyline, and lifting the turn up to the carriage.

Repositioning the carriage was a substantial portion of the lateral-in time in the four blocks using the slackpulling systems, averaging 0.15 to 0.20 min/turn. Repositioning the carriage before going ahead on the turn was not possible with the systems used in Blocks 2 and 3.

Lateral-in was the shortest in Block 2 because the slackline system had virtually no lateral yarding capability. For this block, the element consisted of lifting the turn in the air by tightening the skyline.

Inhaul. The Thunderbird TY-90 had the slowest inhaul speed at 161 m/min in Block 2 and 286 m/min in Block 3.

Unhook. Unhook included lowering the turn at the landing, unhooking the chokers, and raising the chokers back up to the skyline.

In Block 6 the yarder was located on another road above the landing area (Appendix I), thus increasing the distance required for lowering and raising the logs and chokers. This increased the unhook element by about 0.5 min/turn, compared to the other slackpulling system blocks.

In Blocks 2 and 3 the skyline was lowered and raised at the landing in order to unhook the turn. Consequently, these two blocks had the longest unhook times mainly due to the extra 0.5 min/turn it took to raise the chokers by tightening the skyline, compared to the slackpulling system blocks (except for Block 6, see above).

Total delay-free cycle time. Overall, the slackpulling systems were faster than the non-slackpulling systems. The average delay-free cycle times for the two systems were 6.82 and 10.79 min/turn respectively. Accounting for differences in yarding distances, the slackpulling systems were faster overall, averaging 7.04 min/turn at a standardized yarding distance of 400 m compared to 10.22 min for the non-slackpulling systems.

Yarding downhill with the slackpulling system had little effect on the overall turn time. When the total delay-free cycle times at a standardized yarding distance of 400 m are compared for Blocks 5 and 6, yarding downhill averaged only 0.29 min/cycle more than yarding uphill. The difference for the non-slackpulling systems was more substantial. Yarding downhill with the north bend configuration took an average of 1.98 min/cycle more at 400-m yarding distance, compared to yarding uphill with the shotgun configuration. This was partly because of the long distances the crew had to walk to get in the clear when sideblocking. The north bend system did allow considerably greater lateral yarding distances by sideblocking, however.

Delays less than 15 minutes. Contractor 3 in Block 4 had the least delay time at only 0.22 min/cycle and the shortest average time/delay at 1.40 min/delay (Table 9). Block 6 had the highest delay time at 1.02 min/cycle, while Block 1 had the longest delays at 2.77 min/delay. Overall, for all blocks, the averages were 0.66 min/cycle and 2.21 min/delay.

The most common delay category was operational delays (36%), followed by rigging delays (23%).

Regression analysis. Delay-free cycle times, predicted from regression models (Appendix VII), were plotted against slope distances for Blocks 2, 4, 5, and 6 (Figure 12) and lateral distances for Blocks 1 and 3 (Figure 13). (Regression analysis showed lateral distance was the only significant variable to predict cycle time in Blocks 1 and 3.)

DISCUSSION

The lowest cost was observed in Block 4 with the Madill 009 yarder. The higher productivity in this block more than offset the higher combined hourly rate for the yarder and carriage. The higher hourly rate resulted mainly from a larger crew size (except for Block 5) and higher estimated yarder purchase price (except for the TY-90), compared to the other blocks.

The highest productivity in Block 4 was a result of the shortest average cycle time, the shortest in-cycle delays less than 15 min, and the lowest proportion of time/shift in delays greater than 15 min. Block 5 had similar delay-free cycle times (Figure 12) but higher delay time

Table 9. Yarding Delays ≦15 min (from detailed timing study)

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	All
Cycles (no.)	269	134	46	125	300	99	973
Avg. delay time/cycle (min)	0.74	0.88	0.68	0.22	0.53	1.02	0.66
Avg. time/delay (min)	2.77	1.91	2.08	1.40	2.07	2.35	2.21
Proportion of delays (%)							
Mechanical, carriage	13	0	13	0	0	3	5
Mechanical, yarder	8	16	45	46	5	0	11
Operational delay [a]	41	53	24	44	21	31	36
Preparation for road change	0	9	0	0	0	0	1
Delay at the landing [b]	0	13	3	0	24	6	10
Rigging [c]	21	0	15	0	35	43	23
Other [d]	17	9	0	10	15	17	14
Total	100	100	100	100	100	100	100

[a] Common operational delays included: resetting a choker, adding or removing chokers at the landing, skidding line wrapped around the skyline or carriage, bucking a log at the stump, difficulties landing logs, and repositioning the carriage when spotting the turn.

[b] Delays at the landing are times when the rigging crew must wait for some event at the landing to finish before the yarder operator can respond to a signal. Examples are waiting for a truck to pass, waiting for the loader to clear the landing, waiting for the bucker to finish bucking.

[c] Rigging delays include respooling the skidding line, moving a guyline, straightening lines (siwash), repairing skidding line hook or dropline (21% of all delays in Block 1, 29% in Block 6).

[d] Other delays include unknown delays, personal breaks, hooking or removing gear from the rigging.

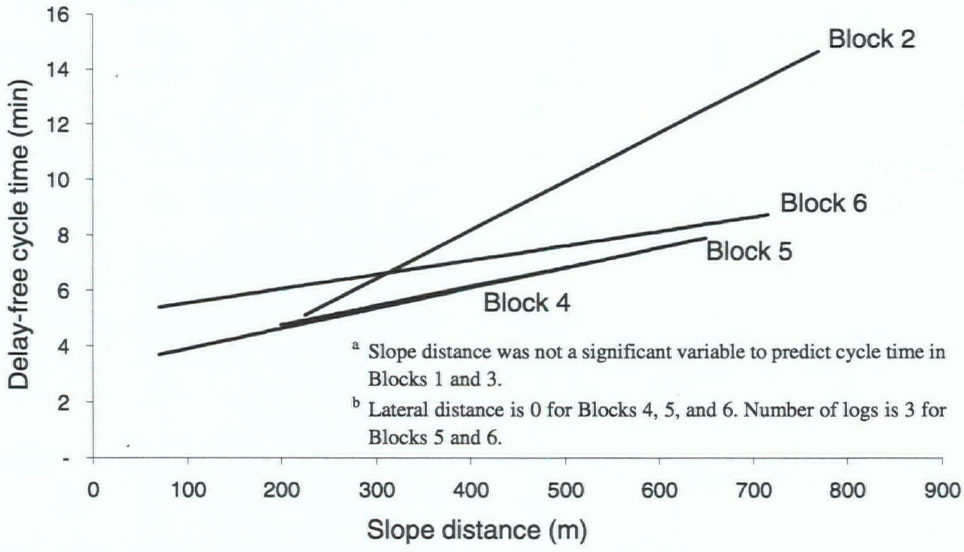

Figure 12. Delay-free cycle time compared to slope distance for Blocks 2, 4, 5 & 6. [a,b]

resulted in lower productivity and higher costs overall. The high productivity in Block 4 occurred in spite of the fact that this block had the smallest tree size and piece size. By yarding tree length logs and more pieces/cycle than other blocks, the crew achieved an average turn volume similar to the other blocks. This contractor operated two chokersetting teams per road and this also contributed to the crew's higher productivity.

Timing and productivity results from this study were compared to those from a highlead yarding study (Kooistra et al. 1990) (Table 10). Even though the average yarding distances were over two and half times greater for the skylines, outhaul and inhaul times were similar due to much faster line speeds with the skyline systems. Choke times (including lowering chokers to the ground, lateral-out, hookup, and lateral-in for the

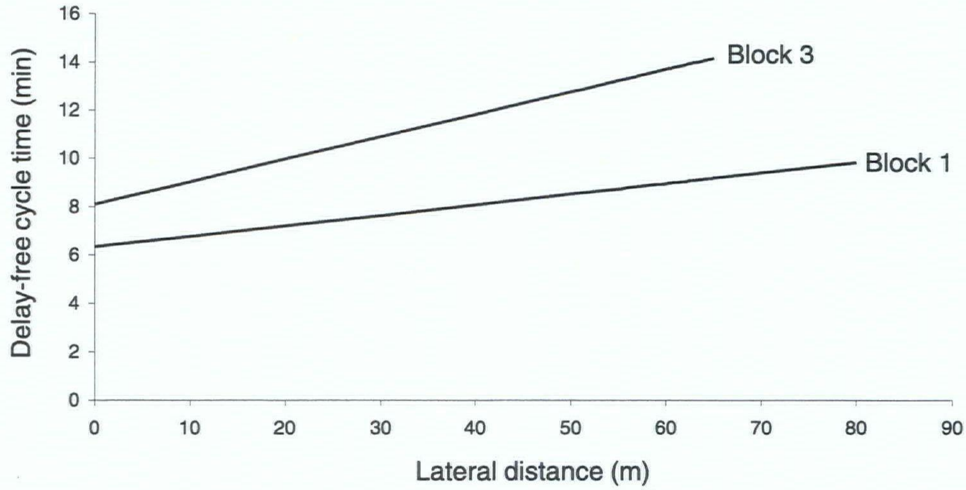

Figure 13. Delay-free cycle time compared to lateral yarding distance for Blocks 1 and 3.

Table 10. Comparison of Highlead and Skyline Yarding

	Highlead [a]	Skyline [b]
Sample size (min)	6899	7891
Minutes/cycle		
Outhaul	0.5	0.7
Choke [c]	3.6	4.2
Inhaul	1.2	1.4
Unhook	1.0	1.1
Total delay free-time	6.3	7.4
Outhaul speed (m/min)	273	508
Inhaul speed (m/min)	114	267
Average yarding distance (m)	136	366
Maximum yarding distance (m)	300	770
Average gross volume/ha (m^3)	776	860
Average net volume/ha (m^3)	n/a	473
Average piece size (m^3)	2.59	1.02
Average logs/turn (no.)	2.1	3.5
Average volume/turn (m^3)	5.48	3.63
Average volume/8-h shift (m^3)	324	110
Proportion of time (%)		
Yarding	79	70
Road changes [d]	10	14
Non-productive	11	16
Total scheduled machine time	100	100

[a] From Kooistra et al., 1990, seven case studies on Vancouver Island.
[b] From this study.
[c] Includes drop chokers to the ground, lateral-out, hookup and lateral-in for skyline.
[d] Includes road changes, landing changes, mobilization and demobilization for skyline.

skylines) for the systems were similar because preset chokers were used on most of the skyline systems studied. The highlead systems spent a higher proportion of time yarding logs and, combined with much larger average log size and higher average volume per turn, the result was much higher productivity.

The average yarding and loading cost of $40.93/m^3 for the skyline systems in this study is much higher than the highlead or grapple yarding costs of $14.92 and $8.85 respectively (including loading) reported by Forrester (1995). However this average skyline cost is still less than recently reported helicopter logging costs for clearcutting at $45.83 (Krag and Clark 1995) and $50.86/m^3 (Bowden-Dunham 1999) (both excluding falling and loading costs). The highest skyline cost in this study, at $51.72/m^3 including loading, approaches the helicopter logging costs of $52.47 reported by Krag and Clark,[11] but is less than Bowden-Dunham's yarding and loading costs of $57.50.

With helicopter harvesting systems, the helicopter is considered in terms of cost/min, and the system is planned, balanced, and maintained to optimize its payload and delay-free yarding time. This strategy becomes critical as the cost of a system increases. If skyline systems were regarded in the same manner, i.e., with the primary objective being to keep the carriage cycling in order to maximize productivity, delays would become unacceptable and strategies would be put in place to prevent them. For example, yarding would not be shut down when a truck is being loaded, and repair

[11] Krag and Clark's yarding cost plus Bowden-Dunham's loading cost of $6.64/m^3.

time would be minimized because spare parts would be on site. System components that consistently break would be repaired, replaced, or modified to eliminate the problem, and thereby eliminate some delays. Also, planned equipment maintenance and replacement, or doing repairs out-of-shift, can prevent many delays.

STRATEGIES TO INCREASE PRODUCTIVITY

Although the physical characteristics of a harvesting area and existing infrastructure often dictate skyline road and landing locations and how logging is conducted, observations made during the study suggest a number of layout, falling, and yarding strategies that could be implemented to increase yarding productivity. Local WCB regulations must be adhered to when applying these strategies.

Layout

Locate landings and anchors to create the minimum clearance for an adequate payload. This will reduce the time to drop the chokers to the ground. Okonski (1998) states: "Deflection in excess of 15% slows production." In this study, anchors were often located to accommodate small areas of poor deflection close to the landings, resulting in large deflections and long drop times over much of the span. The large deflection did not increase payload because the poor deflection area dictated the payload for the entire span. Where possible, locate landings and anchors to create equal but adequate amounts of deflection over the whole span.

Locate skyline roads so that the rigging crew can pull the chokers level or downhill rather than uphill, thereby reducing lateral-out time. Avoid sidehill yarding, and locate skyline roads over ridges rather than draws to reduce uphill lateral pulls.

Falling

Fallers can increase yarding productivity by using directional falling and bucking strategies. Many of these strategies require preplanning and premarking the approximate locations of skyline roads; the benefits increase as lateral yarding distance increases.

Consider yarding tree-length logs in areas with wide distances between skyline anchors and with adequate clearance to the skyline. This will reduce long lateral yarding distances and reduce the number of pieces/turn to be yarded.

Position stems on the ridges and place as few stems as possible in the draws. Yarding out of holes or gullies can dramatically increase turn times because the crew requires more time to walk in to the turn and then to get in the clear.

Place walk logs for the crew perpendicular to the skyline road. This will reduce lateral-out and getting in the clear times, especially in areas with wide lateral yarding, heavy brush, or obstacles. It was observed that a few strategically located walk logs saved the crew a lot of time when setting a turn.

Buck shorter logs and cut stumps lower under the skyline in poor deflection areas to reduce hang-ups. Place logs over holes that could cause hang-ups. (In one situation the crew spent hours fighting hang-ups before using the rigging to position a log over a hole to help redirect the logs.)

Ensure an adequate amount of delimbing is carried out on sites where the trees have heavy crowns. This will reduce obstacles encountered by the rigging crew. Also, because skyline yarding results in full or partial log suspension, fewer limbs are broken off during yarding compared to highlead logging. Increasing the delimbing intensity will shorten unhook times and reduce landing delays.

Yarding

Give deflection line and payload analysis information to the crew; and, if necessary, provide training to interpret the information. In the study, some contractors gave this information to the crew, but others did not. In one situation, when the crew changed yarding roads they discovered that there was no deflection and had to change roads again.

Use two separate teams on the skyline road. This technique was very efficient because less time was spent in lateral-out, hooking the turn, and delays. It cannot be used everywhere, but where possible, it can improve productivity. The terrain must be such that any logs dislodged by the upper crew would not create a hazard for the lower crew. This technique also provides a more even flow of wood to the landing, rather than high production rates near the front of the road and low rates at the back. Also, the crew nearer the landing can be generating turns while the crew furthest out is still walking to (or from) its work site. The technique should be less tiring on the chokersetters as the time between turns increases for each team.

Preset chokers to eliminate or reduce the time waiting for the crew to untangle chokers, carry the chokers to the logs, and hook the logs. The only time required during hookup when presetting is the time to carry the hook to the chokers and hook them to it. One man can usually carry the hook unless the lateral distance is great or uphill, and the rest of the crew can preset the next turn.

Use the haulback to pull slack for lateral yarding. Lack of suitable skyline anchors produced very wide lateral yarding in some areas. Setting up the haulback line to pull slack aided the crews in these situations.

Provide a powersaw winch for the hooktender. This allows him to perform some rigging work that would otherwise require yarding to stop and/or extra manpower.

Ensure adequate line is available for the distance to be yarded. In one block, the skidding line was too short to reach the logs at the back of the block. A long extension was hooked between the chokers and the carriage and used to move the logs within reach of the skidding line. The extension was then removed and the logs were rehooked. This procedure doubled the cycle time.

Manage the operation to reduce delays and downtime. Contractor 3's operations in Block 4 were distinguished by the low amount of delay time. With all delays combined, only 8% of SMH in Block 4 were spent in delays, while the contractors on the other blocks averaged 20%. The higher productivity in Block 4 can be directly attributed to the low amount of delay time. The equipment and rigging required for skyline systems are more sophisticated and complex than highlead systems, and have more potential for incurring delays if they are not operating well. The longer yarding distances magnify the effect of any yarder or rigging problems. Contractor 3 was well organized and prepared to handle minor problems quickly.

CONCLUSIONS

Long-distance skyline operations require good management to be efficient; otherwise, the consequences are low productivity and high costs relative to other cable systems. In this study in old-growth on steep slope terrain, operators' productivities varied up to 61%. The average yarding productivity for the six blocks studied was 110 m^3/8-h shift including all moves and road changes, but productivity ranged from 91 to 147 m^3/shift. Overall, yarding and loading cost was $40.93/$m^3$ and ranged from $34.51 to $51.72.

The motorized slack-pulling carriage system was found to be more productive than the non-slackpulling carriage systems. Yarding uphill with gravity return (shotgun) was more productive than logging downhill using a haulback. Yarding downhill with the north bend system was the least productive of all systems studied. The use of preset chokers reduced hookup time and increased productivity, compared to the blocks where they were not used. The faster outhaul speed of the shotgun system reduced outhaul time and increased productivity compared to the haulback systems. The inhaul speed on the Thunderbird TY-90 was very slow when yarding uphill compared to the other yarders in the study.

The contractor with the highest productivity and the lowest cost incurred much less delay time than the other contractors. This contractor also used two separate teams to set turns on the skyline road, i.e., whenever feasible and safe.

An effective way to improve productivity is to reduce delays. Managing the skyline system like a helicopter logging show in terms of high costs/min, and managing the total system to keep the carriage cycling back and forth as much as possible will improve system productivity.

Yarding with long-distance skyline systems is considerably more expensive than with highlead and grapple systems, and areas for their application should be chosen carefully. In areas with high road construction costs and/or environmental concerns, road densities can be reduced by using these systems. Skyline yarding may be less expensive than helicopter logging and therefore it should be considered in appropriate locations.

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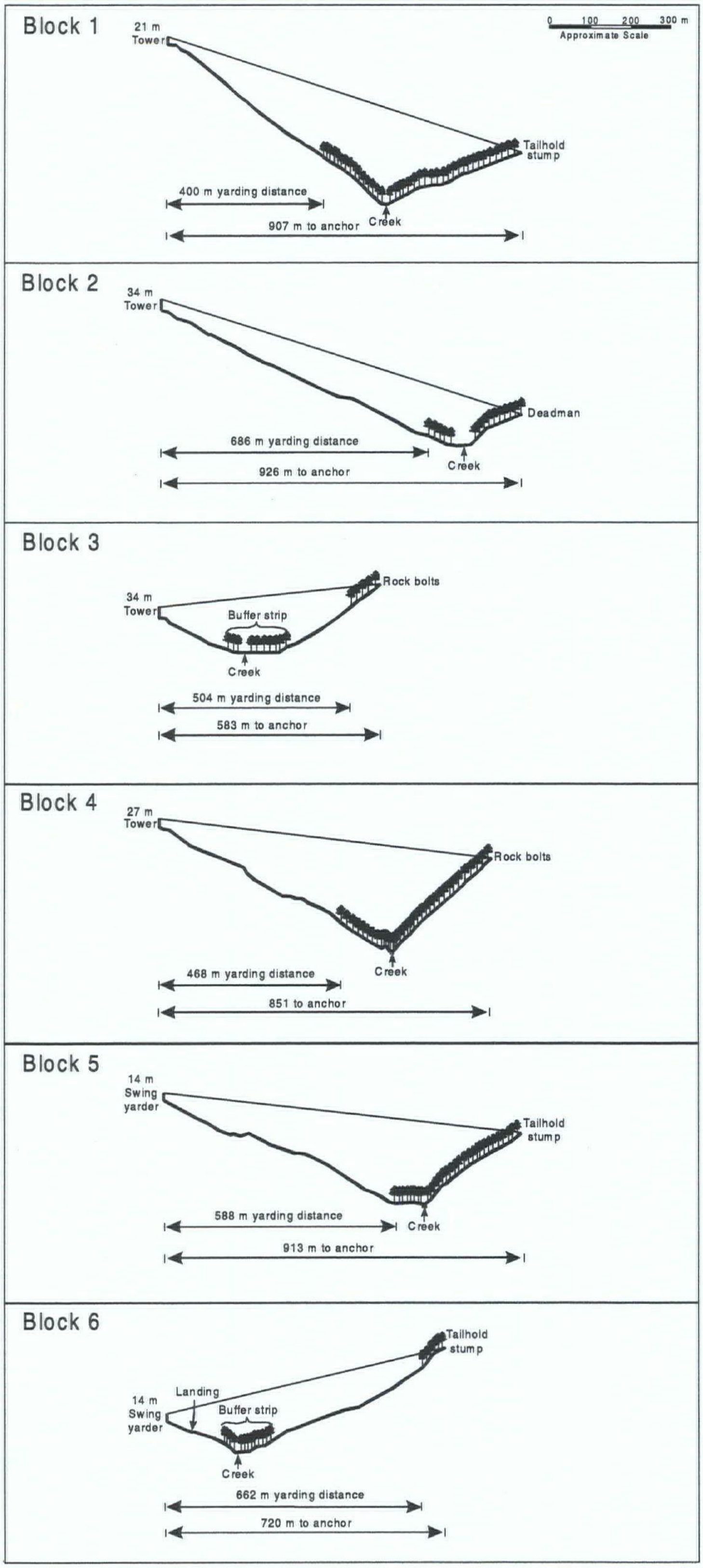
Appendix I

Examples of Ground Profiles for Each Block



Appendix II

Yarder and Motorized Slack-pulling Carriage Specifications [a]

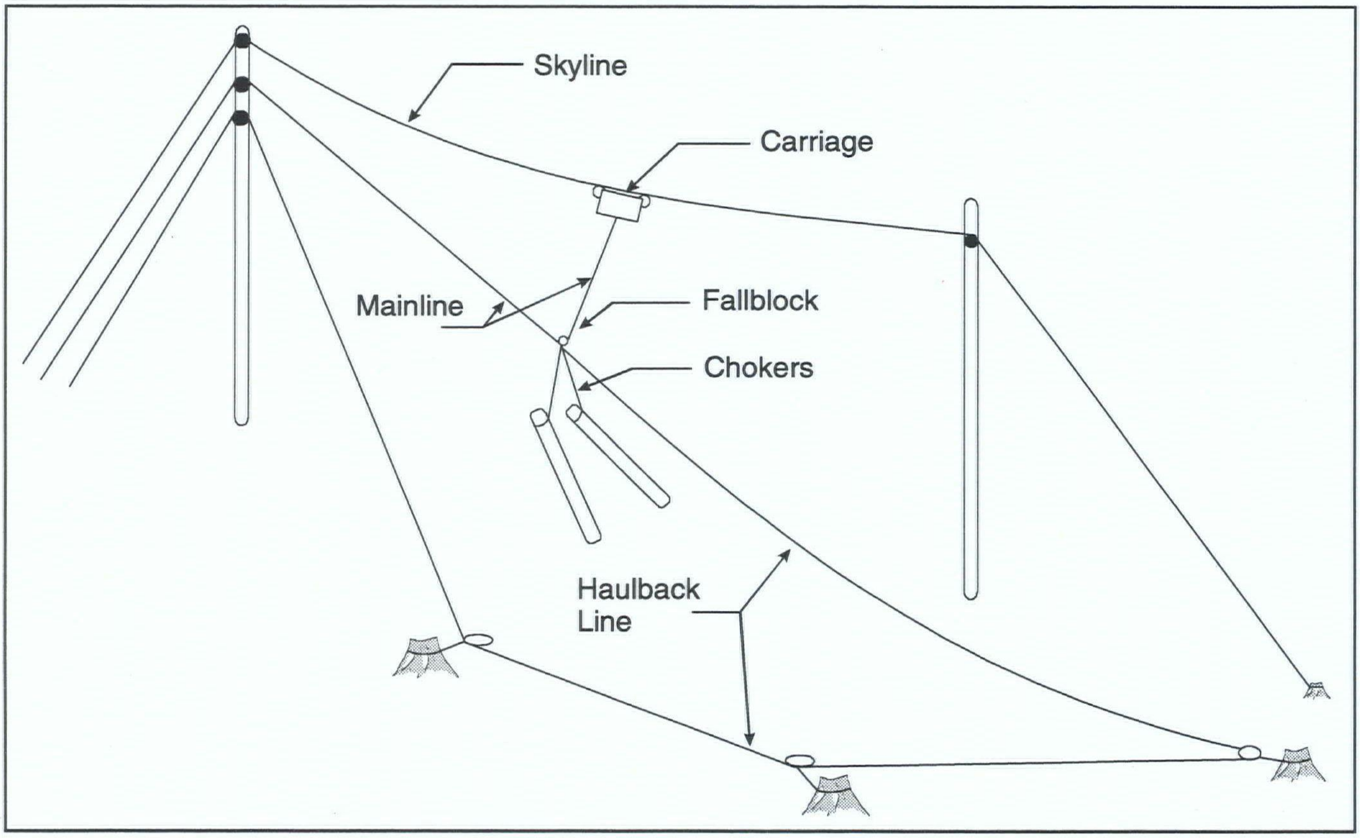
Yarder	Thunderbird TMY-70	Thunderbird TY-90	Madill 009	Washington 78SL
Tower height (m)	21	34	27	14
Engine power (kW)	321	336	317	170 [c]
Maximum mainline line pull (kN)	497	686	220 [b]	165
Maximum mainline line speed (m/s)	21	15	15 [b]	12
Skyline diameter (mm)	29	35	29 [d]	29 [d]
Weight with lines (kg)	42 000	61 000	55 000	42 000

Motorized slack-pulling carriage	Eagle II	Eagle III
Engine power (kW)	11	21
Approximate weight (kg)	1180	1634
Slack puller line speeds (m/s)	1.8 & 2.2	1.8 & 2.2
Load capacity (kg)	6810	9080

[a] From manufacturer's specification sheet, unless noted otherwise.
[b] Specifications for the haulback are reported because the yarder was modified to use the mainline as the skyline, and the haulback as the skidding line.
[c] Specification for stock engine (671 Jimmy) which was replaced with a 692T turbo Jimmy.
[d] Actual line size during study.

Appendix III

North Bend Skyline System



Appendix IV

Assumptions Used in the Cost Calculations

For costing, the wire ropes used were the largest diameter specified by the manufacturer for each drum, except as noted below. All skylines were assumed to be Power Pac™ [1] wire rope with 600-m extensions added to the manufacturer's specified drum capacity. IPS[2] grade wire rope was used for all other lines except for the Washington 78SL where smaller diameter swaged lines were used for the mainline and haulback in order to increase this machine's drum capacities. Line life was considered to be two years for the skylines, strawlines, and guylines, while a one-year life was used for the skidding lines and haulback lines. Choker life was one week.

Different log loaders were used by the contractors, but to simplify costing only two loaders were used for the study. A Linkbelt LS4300 hydraulic loader was used for Blocks 2 to 6, and a Caterpillar 950F front-end loader (FEL) was used for Block 1 where the FEL forwarded logs to another landing for loading. For costing purposes it was assumed that the loader and crew worked the same shift as the yarder, even though this was not always the case. For example, the loader operator for Block 1 worked an overlapping shift when the yarder was double-shifted, and the loaders in all blocks sometimes did not work on days when there was no yarding (e.g., rigging days).

The number of yarding crew members varied throughout the study, but for costing purposes an average whole number crew size was used.

Costs exclude falling, fire protection, supervision, crew transportation, additional equipment for machine moves, first aid coverage, taxes, profit, and any premiums paid for service time or overtime. Although some crews occasionally worked late or on weekends in order to rig-up for yarding, cost calculations assumed all labour was paid at straight time rates. Costs include yarding, loading, moving, set-up and tear down, road changes, helicopter time, and installation of rock bolts.

Rock bolts were used for skyline anchors on several blocks in the study, while deadmen were used in one block. To standardize the costs for all blocks, it was assumed that 25% of all skyline roads in all blocks required rock bolts. Four bolts per anchor were used at a cost of $2645/installation (Appendix V). The wide lateral yarding capability of the slackpulling carriage system allowed the skyline anchors to be spaced further apart than with the other systems thus reducing the number of rock bolt installations and providing a reduciton in costs (Table 4).

Helicopters were used to help string lines and move rigging equipment in most blocks. A helicopter rate of $774/h was used for costing. Block 2, the only block that had road access to the back end of the block, and Block 3, had no helicopter usage recorded. A line horse[3] was used to transport wire rope extensions and help rig-up in three of the blocks. A charge-out rate of $75/h was used for this machine. Only the time spent working in the blocks was charged to these machines for costing; time spent traveling to and from the blocks was not included.

An allowance of $50/day/powersaw was included in the costs, with allowance for one powersaw for the chaser/landing bucker, ½ powersaw for the hooktender, and one powersaw for the second loader, as applicable to each block.

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[1] A stronger, denser type of rope.

[2] Improved plow steel.

[3] A winch set from an old yarder mounted on a truck.

Appendix V

Costs for Rock Bolt Anchors

Cost to supply and install four rock bolts for a skyline anchor:
(does not include cleaning of rock or preparation of site, if required)

Two men, 1 day	16 h @ $25/h	$400
Wage/benefit loading	39%	156
Rock bolts (1.5 m × 32 mm)	4 @ $110 each	440
Polyethylene resin	3 tubes/hole × 4 holes @ $50/tube	600
Helicopter time	1 h @ $774/h	774
(does not include ferry time from town)		
Portable rock drill rental	1 week @ $275/week	275
Total for 4 bolts		$2 645

Figure V-1. Drilling holes with a portable drill for rock bolt anchors in Block 4.

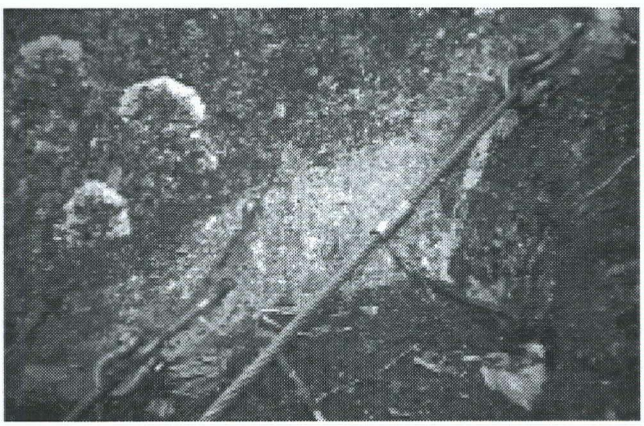

Figure V-2. Installed rock bolts in Block 3.

Appendix VI

Machine Costs [a]

	Thunderbird TMY-70 tower yarder 5 person crew [b] (Block 1)	Thunderbird TY-90 tower yarder 5 person crew [b] (Blocks 2 & 3)	Madill 009 tower yarder 7 person crew [b] (Block 4)	Washington 78SL swing yarder 7 person crew [b] (Block 5)	Washington 78SL swing yarder 6 person crew [b] (Block 6)
OWNERSHIP COSTS					
Purchase price (P) [c] $	850 000	1 111 200 [d]	985 000 [e]	720 000 [f]	720 000 [f]
Expected life (Y) y	12	12	12	12	12
Expected life (H) h	17 280	17 280	17 280	17 280	17 280
Scheduled hours/year (h)=(H/Y) h	1 440	1 440	1 440	1 440	1 440
Salvage value as % of P (s) %	30	30	30	20	20
Interest rate (Int) %	10.0	10.0	10.0	10.0	10.0
Insurance rate (Ins) %	2.5	2.5	2.5	2.5	2.5
Salvage value (S)=((P•s/100) $	255 000	333 360	295 500	144 000	144 000
Average investment (AVI)=((P+S)/2) $	552 500	722 280	640 250	432 000	432 000
Loss in resale value ((P-S)/H) $/h	34.43	45.01	39.90	33.33	33.33
Interest ((Int•AVI)/h) $/h	38.37	50.16	44.46	30.00	30.00
Insurance ((Ins•AVI)/h) $/h	9.59	12.54	11.12	7.50	7.50
Total ownership costs (OW) $/h	82.39	107.71	95.48	70.83	70.83
OPERATING COSTS					
Annual wire rope (wc) $	72 400	99 700	85 400	70 300	70 300
Rigging & radio (rc) $	10 000	10 000	10 000	10 000	10 000
Rigging & radio life (rh) h	6 000	6 000	6 000	6 000	6 000
Fuel consumption (F) L/h	30	50	36	35	35
Fuel (fc) $/L	0.40	0.40	0.40	0.40	0.40
Lube & oil as % of fuel (fp) %	10	10	10	10	10
Annual tire consumption (t) no.	1.0	1.0	1.0	-	-
Tire replacement (tc) $	825	825	825	-	-
Track & undercarriage replacement (Tc) $	-	-	-	35 000	35 000
Track & undercarriage life (Th) h	-	-	-	9 000	9 000
Annual operating supplies (Oc) $	10 000	10 000	10 000	10 000	10 000
Annual repair & maintenance (Rp) [g] $	72 000	86 000	56 000	60 000	60 000
Shift length (sl) h	8.0	8.0	8.0	8.0	8.0
Wages $/h [h]					
Operator	24.12	24.12	24.12	24.12	24.12
Hooktender	26.12	26.12	26.12	26.12	26.12
Rigging slinger (s)	24.12	24.12	48.24 [i]	48.24 [i]	24.12
Chaser	-	-	21.99	21.99	21.99
Chaser/landing bucker	24.77	24.77	-	-	-
Chokersetter	21.40	21.40	21.40	21.40	21.40
Second loader	-	-	24.77	24.77	24.77
Total wages (W) $/h	120.53	120.53	166.64	166.64	142.52
Wage benefit loading (WBL) %	39	39	39	39	39
Wire rope (wc/h) $/h	50.28	69.24	59.31	48.82	48.82
Rigging & radio (rc/rh) $/h	1.67	1.67	1.67	1.67	1.67
Fuel (F•fc) $/h	12.00	20.00	14.40	14.00	14.00
Lube & oil ((fp/100)•(F•fc)) $/h	1.20	2.00	1.44	1.40	1.40
Tires ((t•tc)/h) $/h	0.57	0.57	0.57	-	-
Track & undercarriage (Tc/Th) $/h	-	-	-	3.89	3.89
Operating supplies (Oc/h) $/h	6.94	6.94	6.94	6.94	6.94
Repair & maintenance (Rp/h) $/h	50.00	59.72	38.89	41.67	41.67
Wages & benefits (W•(1+WBL/100)) $/h	167.54	167.54	231.63	231.63	198.10
Total operating costs (OP) $/h	290.20	327.68	354.85	350.02	316.49
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	372.59	435.39	450.33	420.85	387.32

[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, or premiums for overtime and service time, and are not the actual costs for the contractor or company studied. [b] Crew does not include loader operator. [c] Purchase prices provided by Finning, Parker Pacific, and Madill. [d] Includes $11 200 for shotgun carriage and northbend rigging. [e] The Madill 009 is no longer manufactured; this price is estimated by Madill to produce a similar machine. [f] The Washinton 78SL is no longer manufactured; the purchase price used is for a Madill 120. [g] Annual costs for repairs and maintenance were provided by the contractor, equipment suppliers, and estimated by FERIC. [h] June 15, 1998 IWA labour rates. [i] Two rigging slingers.

Appendix VI

Machine Costs [a]

	Eagle II carriage (Block 1)	Eagle III carriage (Blocks 2 to 6)	Caterpillar 950F front-end loader (Block 1)	Linkbelt LS4300 hydraulic loader (Blocks 2 to 6)
OWNERSHIP COSTS				
Purchase price (P) [b] $	78 000	85 000	305 000	450 000
Expected life (Y) y	5	5	10	10
Expected life (H) h	7 200	7 200	14 400	14 400
Scheduled hours/year (h)=(H/Y) h	1 440	1 440	1 440	1 440
Salvage value as % of P (s) %	10	10	30	30
Interest rate (Int) %	10.0	10.0	9.0	9.0
Insurance rate (Ins) %	2.5	2.5	3.0	3.0
Salvage value (S)=((P•s/100) $	7 800	8 500	91 500	135 000
Average investment (AVI)=((P+S)/2) $	42 900	46 750	198 250	292 500
Loss in resale value ((P-S)/H) $/h	9.75	10.63	14.83	21.88
Interest ((Int•AVI)/h) $/h	2.98	3.25	12.39	18.28
Insurance ((Ins•AVI)/h) $/h	0.74	0.81	4.13	6.09
Total ownership costs (OW) $/h	13.47	14.68	31.35	46.25
OPERATING COSTS				
Fuel consumption (F) L/h	1.5	1.5	28.0	35.0
Fuel (fc) $/L	0.40	0.40	0.40	0.40
Lube & oil as % of fuel (fp) %	10	10	15	15
Annual tire consumption (t) no.	-	-	1.0	-
Tire replacement (tc) $	-	-	4 000	-
Track & undercarriage replacement (Tc) $	-	-	-	35 000
Track & undercarriage life (Th) h	-	-	-	8 000
Annual operating supplies (Oc) $	-	-	1 500	1 500
Annual repair & maintenance (Rp) [c] $	10 000	10 000	23 500	26 000
Shift length (sl) h	8.0	8.0	8.0	8.0
Operator wages (W) [d] $/h	-	-	23.46	23.46
Wage benefit loading (WBL) %	-	-	39	39
Fuel (F•fc) $/h	0.60	0.60	11.20	14.00
Lube & oil ((fp/100)•(F•fc)) $/h	0.06	0.06	1.68	2.10
Tires ((t•tc)/h) $/h	-	-	2.78	-
Track & undercarriage (Tc/Th) $/h	-	-	-	4.38
Operating supplies (Oc/h) $/h	-	-	1.04	1.04
Repair & maintenance (Rp/h) $/h	6.94	6.94	16.32	18.06
Wages & benefits (W•(1+WBL/100)) $/h	-	-	32.61	32.61
Total operating costs (OP) $/h	7.60	7.60	65.63	72.18
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	21.08	22.29	96.98	118.43

[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, premiums for overtime and service time, and are not the actual costs for the contractor or company studied. [b] Purchase prices provided by Finning, Parker Pacific, and Madill. [c] Annual costs for repairs and maintenance were provided by the contractor, equipment suppliers, and estimated by FERIC. [d] June 15, 1998 IWA labour rates.

Appendix VII

Regression Models for Delay-Free Cycle Times

Model description	Independent variable	Range	Coefficient	Intercept	Standard error of the estimate	Number of observations	R^2
Block 1				6.3285	1.71	269	0.15
	LATD	0–8 m	0.0438				
Block 2				1.1646	2.19	134	0.49
	SD	225–770 m	0.0175				
Block 3				8.0878	2.16	46	0.29
	LATD	0–65 m	0.0935				
Block 4				3.3702	0.87	125	0.45
	LATD	0–40 m	0.0288				
	SD	200–535 m	0.0069				
Block 5				2.3296	1.64	300	0.34
	SD	70–650 m	0.0073				
	LATD	0–80 m	0.0350				
	LOGS	1–10 logs	0.2791				
Block 6				3.6724	1.92	99	0.33
	SD	265–716 m	0.0052				
	LATD	0–75 m	0.0305				
	LOGS	1–7 logs	0.4465				

Independent variable	Abbreviation	Definition
lateral distance	LATD	Horizontal distance perpendicular to the skyline, from the skyline to the hook point on the farthest log in a turn.
slope distance	SD	Slope distance from the yarder to the point on the ground under the skyline where the carriage was stopped during outhaul.
number of logs	LOGS	Number of logs yarded to the landing.

Example of predicted cycle time calculation

Model	Block 5
Equation	cycle time = 0.0073 (SD) + 0.0350 (LATD) + 0.2791 (LOGS) + 2.3296
Values	slope distance = 365 m, lateral distance = 16 m, number of logs = 3
Calculation	cycle time = 0.0073 (365) + 0.0350 (16) + 0.2791 (3) + 2.3296
Predicted cycle time	6.39 min

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