Operational Analysis of Partial Cut and Clearcut Harvesting Methods in North-central Interior ICH/ESSF Mountain Forests

Final Report to the Robson Valley Enhanced Forest Management Pilot Project (EFMPP)

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EXECUTIVE SUMMARY

In 1998, the University of Northern British Columbia (UNBC) in cooperation with the Ministry of Forests Robson Valley Forest District Small Business Enterprise Forestry Program and a local industry partner (Canfor) initiated the Operational Analysis of Partial Cut and Clearcut Harvesting Methods in North-central Interior ICH/ESSF Mountain Forests project. The goal of this project is to monitor and assess harvesting activities in the three study sites: East Twin, Minnow, and Bearpaw. East Twin creek is the only site harvested to date, with the other sites scheduled for harvest in 2001. East Twin Creek study compares two ground based skidding (0% and 70% retention) and one clearcut cable yarding operation in old growth (250 years or older) hemlock cedar stands, 35 km west of McBride, B.C.

The objectives were to assess planning and harvesting productivities and costs; assess stand damage levels; and identify ways to improve operational planning and implementation of partial cutting silvicultural systems in Interior Cedar-Hemlock ecosystems. UNBC monitored productivities functions were derived to predict felling, skidding, and yarding productivities and costs over a range of operating conditions.

Between February and April 2000, two contractors harvested two study blocks containing a total of three treatments. Contractor A harvested two ground-based skidding treatments (0% and 70% retention) and Contractor B harvested the clearcut cable treatment. UNBC collected shift- level and detailed timing data on all skidding, yarding, and felling activities, shift level data for processing and loading, summarized planning requirements and costs for each of the study treatments, used shift level data to calculate the and surveyed stand damage after harvesting for the 70% retention treatment.

The 70% retention treatment clearly required more intensive planning and fieldwork, requiring 4.9 and 3.8 times more planning and layout effort than the ground-based and cable clearcut treatments respectively. Costs of planning and layout were calculated at $\$2.62/m^3$ for the 70% treatment, $\$0.68/m^3$ for the cable clearcut treatment, and $\$0.53/m^3$ for the ground based clearcut treatment.

Manual felling was the only method used for all harvest units because of large tree size (Avg. diameter was >53.2cm) and steep slopes. Felling in the 70% retention was only marginally higher than the ground-based clearcut at $\$2.02/m^3$ and $\$2.01/m^3$ respectively. The lowest felling cost was in the cable portion of the clearcut at $\$1.11/m^3$. This lower cost may illustrate the productivity of different fallers as a different faller fell the ground-based treatments than the cable treatment.

Ground based skidding was completed with a line skidder. In the clearcut treatment a production rate of $21.69m^3$/hr was achieved at a cost of $\$4.14/m^3$. The production rate was lower in the 70% retention at $20.05m^3$/hr with a cost of $\$4.48/m^3$. This higher cost may be the result of the average skidding distance being approximately 100m longer.

Yarding was completed by a tower yarder used an adapted running skyline system with a non-slackpulling carriage. Yarding was downhill with distances ranging from 35 to 225 meters with an average distance of 125 meters. The unit cost for yarding was $\$7.73/ m^3$, which is 72.5% more expensive than skidding in the group selection and 86.7% higher than skidding in the ground-based clearcut. The cable system had a production rate of $24.27m^3$/hr.

Processing was done by manual means on the landing. The costs were highest in the 70% retention at $\$1.54/m^3$, followed by the cable treatment at $\$1.15/m^3$. The ground-based clearcut treatment had the lowest processing cost at $0.96/m^3. The higher cost in the cable treatment may be the result of the cedar being processed for both saw logs and post and rail timber. In the group selection and ground-based clearcut, the timber was only processed for saw logs because of the lack of experience of Contractor A in processing defective cedar.

Loading was completed by a front-end loader in the ground-based treatments and a heel-boom loader in the cable treatment. Loading costs were the highest in the group selection at $5.32/m^3. The cable and ground-based clearcut both had lower costs at $5.01/m^3 and $3.33/m^3, respectively. The cable clearcut had higher costs than the ground-based clearcut largely due to higher equipment costs per hour, although a heel-boom loader showed a greater productivity (m^3/hr) than the group selection. Contractor B chose a heel-boom loader, as it requires less operating space on the landing then a front-end loader.

Overall planning, falling, skidding/yarding, processing, and loading costs were calculated at $10.98/m^3 for the ground-based clearcut, $15.68/m^3 for the cable clearcut, and $15.97/m^3 for the ground-based 70% retention treatment. Relative to the other treatments the ground-based clearcut had lower planning and layout, skidding, processing, and loading costs than the other treatments. The 70% retention had the highest cost in all phases except skidding/yarding where the cable system had the highest costs. Ground-based clearcutting is clearly the most cost effective option for harvesting. The 70% retention treatment resulted in cost that are 45% higher than those of the ground-based clearcut. Although the 70% retention treatment was the most expensive it does provide more options when managing non-timber values.

In the 70% retention treatment stand damage was assessed post harvest. It was found that 73% of the total damage occurred within 5 meters from the centre of a skid trail. The skid trail was a total of 5 meters wide. The remaining 27% of the damage occurred within 5 meters from the edge of harvest openings.

During the course of the harvesting operations, UNBC researchers identified opportunities for potentially improving the operational efficiency and/or cost of harvesting in ICH stands. In the case of layout and planning, harvest group layout to facilitate felling and straighter skid trails could reduce stand damage while improving harvesting efficiency. For cable systems, layout should ensure that deflection exists from planned tower locations. Ensure no unnecessary non-productive delays by developing work plans at the beginning of each shift. And finally, the contractors should be aware of current markets for cedar and other species before harvesting. This will ensure that a market exists for the timber and that the highest commercial volume is being extracted.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

Forest management in British Columbia is rapidly changing due to increasing emphasis on social goals that include the management of non-timber resources such as visual quality and wildlife habitat. The use of partial cutting has been considered as an alternative method for achieving these management goals. As with any new management tool, knowledge and experience with partial cutting is limited for many of BC's forest ecosystems. A study by Thibodeau et al (1996) reported logging productivity and costs of partial cut treatments in interior cedar hemlock (ICH) stands at Date Creek in the northwest of BC, however, the study occurred in a second growth stand with an age of 130-years and moderately gentle terrain. Thus it is not clear if the study can be extrapolated to wet-belt ICH forests in east-central BC where slopes are steeper and the forests are 250 years or older.

The wet ICH subzones are located at elevations lower than 1200 m and primary species are western red cedar (*Thuja plicata*), with minor components of western hemlock (*Tsuga herterophylla*), hybrid white spruce (*Picea glauca x engelmannii*), and subalpine fir (*Abies lasiocarpa*). The ESSF zone is located at elevation above 1200 m and the stand is composed of uneven-aged subalpine fir (*Abies lasiocarpa)* and Englemann spruce (*Picea engelmannii*).

In order to improve this knowledge, the University of Northern British Columbia is examining partial cutting at various retention levels in the ICH and Englemann spruce subalpine fir (ESSF) at study areas located on the eastern rim of the central interior plateau of BC.

Two ICH sites are located at Minnow Creek and East Twin Creek between Purden Lake and McBride BC. The Minnow Creek site contains three treatment units of 0%, 30% and 70% retention and will be harvested using ground skidding. East Twin Creek site has already been harvested and contains treatments of 0% and 70% retention. The 0% retention treatment was harvested using both ground-based and cable harvesting systems. The ESSF research site is a helicopter block in the Prince George Forest District on Bearpaw Ridge, located between Purden Lake and McBride BC. Treatments consist of large group selection (1 hectare in size), small group selection (0.25 hectare openings), and single-tree selection. The productivity and costs of partial cutting will be compared with those from a nearby clearcut.

The primary goal of this study is to assess the operational and economic feasibility of partial cutting in ESSF and ICH stands. The following objectives were established to achieve this goal:

- Determine the logging planning/layout cost and techniques required for various retention levels of partial harvesting operations;
- Determine logging costs ($\$/m^3$) for three different retention treatments: (0%, 30%, and 70%) with ground-based, cable, and helicopter logging systems;
- Investigate the amount of stand damage to residual stands from partial cutting; and
- Develop recommendations for partial cutting practices to improve logging efficiency and minimize impacts on residual stands and soils.
- Examine the utilisation of cedar harvested.

This report includes the final results of a partial cut and a clearcut study in East Twin Creek near McBride, BC, administered by the Small Business Forest Enterprise Program (SBFEP) of the Robson Valley Forest District. Two ground skidding (0% and 70% retention) and one clearcut cable yarding operations was studied.

II. STUDY METHODS

Site and harvesting systems

The research was conducted on sites in the ICHwk3 biogeoclimatic zone of the Robson Valley Forest District in the Prince George Forest Region. The site was located on the East Twin Forest Service Road, 35 km west of McBride, BC. The treatment units are located at 900 meters in elevation and have a northwest aspect. Table 1 summarizes terrain and stand characteristics for each treatment. While the treatment area for the group selection harvest unit is 8.7 hectares (ha) the actual harvest area is 2.0 ha in size, composed of ten openings averaging 0.2 ha.

Table 1. Site and stand description.

Harvesting system	Ground skidding		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Treatment size (ha)	8.7	1.1	6.7
Harvested area (ha)	2.1	1.1	6.7
Slope (avg.)	0-50% (20%)	0-30% (15%)	30-130% (55%)
Species (%)			
Western red cedar	87	79	90
Subalpine fir	3	10	3
Englemann spruce	10	5	2
Western hemlock	0	6	5
Stems/ha[a]	404.7	424.3	424.3
Avg. DBH (cm)[a]	56.2	53.2	53.2
Avg. ht (m)[a]	36.7	33.5	33.5
Gross vol. (m^3/ha)[a]	1074.6	908.0	908.0
Net merchantable vol. (m^3/ha)[b,c]	349.0	441.6	433.0

[a] Provided by the BC MOF Cruise data.
[b] The low net merchantable volume resulted from high decay, waste, and breakage.
[c] The net merchantable volume was calculated from the BC MOF Scale data.

Two contractors participated in the SBFEP sales; the first contractor harvested the ground-based treatment units and the second contractor harvested the cable unit. The contractors' harvesting equipment profiles are shown in Table 2. The equipment of Contractor A reflects a conventional ground-based system used to harvest old-growth ICH. Contractor B, a subcontractor of Contractor A, was hired to clearcut the cable block for the 100% removal silvicultural treatment. Contractor A hired Contractor B because of time constraints and other previous commitments. At the time of this study, partial cutting was new to Contractor A and he used his existing equipment and staff to fulfill the requirements of partial cutting.

During February and March of 2000, Contractor A harvested two treatment units, the group selection (70% retention) and clearcut (0% retention), using a ground-based harvesting system consisting of hand felling, skidding with rubber-tired and tracked line skidders, manual delimbing/bucking, and loading with a front end wheel loader. Contractor B harvested one treatment unit, the cable clearcut block (100% removal), using an adapted running skyline system consisting of hand felling, yarding with a tower yarder, manual delimbing/bucking, and loading with a heel boom log loader.

Table 2. Equipment and labour complement for contractors.

Contractor	Contractor A	Contractor B
Harvesting system	Ground-based	Cable
Silvicultural treatment	Clearcut and group selection	Clearcut
Felling	1 hand feller	1 hand feller
Skidding / yarding	John Deere 640 D line skidder	Madill J7C tower yarder
Skid trail and landing construction	Caterpillar D6D line skidder	Used pre-existing landing
Processing / bucking	1 bucker	1 bucker
Loader	John Deere 644E front end log loader	Barko 450 heel boom log loader

Data collection

Under the direction of SBFEP staff, UNBC researchers and contractors completed all preliminary layout and cruising. Individual trees were marked for removal in groups based on topography and skid trail layout. Trees on skid trails contributed to the prescribed stand density reductions in both harvest units. Haul roads and openings for landings were pre-existing for both sites and in the group selection, skid trail location was suggested but the final decision of skid trail location was left with contractor. Harvesting operations took place from February to April 2000.

There were three methods used to collect time data on logging operations: shift level, detailed, and activity sampling. On a daily basis, machine operators filled out shift-level data forms. These forms described their daily activities, which include shift length, break time, delay time, and types of delay. To collect detailed timing information for skidding, felling, and yarding, UNBC researchers used a Ranger 3100 data logger to time the components of each harvesting process. During the detailed-timing phase, the skidding cycle was sub-divided into cycle elements (travel empty, repositioning, choking, travel loaded, etc.), and skidding distances and pieces per cycle were also recorded. A similar procedure occurred for yarding cycles using different cycle elements. Hand felling of each treatment was also timed by the Ranger 3100 and subdivided into cycle elements. DBH was recorded with the Ranger 3100 but only when WCB safety regulations could be met. This provided the necessary information on productive and non-productive time for each machine during the study. The landing activity sampling measured any delays on the landing that were caused by unbalanced production activities. For each treatment, a landing was randomly sampled twice during harvesting once before and after 12:00 pm. The equipment and personnel on the landing were then observed for an hour. In that hour, sampling intervals were set at 20 seconds to ensure the accuracy of the data as recommended by Olsen and Kellogg (1983). The equipment and personnel on the landing were classified as working, delayed, or not working on the landing. In the case of the bucker, refuelling and filing time was also noted.

Harvesting costs were calculated using the Forest Engineering Research Institute of Canada's (FERIC) standard costing methods and were based on local standard contractor rates for workers. Equipment purchase prices were based upon the costs for similar models being produced today, as all the equipment used in the study is no longer made. The salvage value was set at a standard 30% (Appendix 1). The costs do not include supervision, overhead, profit, and risk allowances.

Harvested volumes used for unit cost calculations ($\$/m^3$) were obtained from BC Ministry of Forest (BCMOF) weigh scale records. The volume for each treatment was then determined from the BCMOF weigh scale data by hauling dates. Once the treatment volume was known, the average volume per tree was calculated by dividing the volume per treatment by the number of commercial trees (>17.5 cm in DBH) cut in that treatment. The number of trees per unit was calculated from shift level data. The unit cost was then calculated using the volume per tree, number of trees per cycle, cycle time, and cost per hour for the equipment and/or labour.

A multiple regression analysis was completed for felling and primary transportation elements of the harvesting operation. This process first identified the significant variables involved in felling and primary transportation. Once the significant variables were identified, an equation to estimate productive cycle time for each component was developed. This equation allows for the estimation of productive time from on site factors such as tree diameter or skidding distance.

Stand damage was quantified by the post harvest examination of residuals and boundary trees for all treatments. Damage was quantified in three main categories; root, stem, and crown damage. Root and stem damage was measured using a tape measure. The width, depth, and length of each scar or gouge was recorded as well as its orientation and location on the tree in comparison to the closest opening or skid trail. The scar area will be calculated from the width and length values measured. Crown damage was measured by the use of a clinometer to measure the proportion of live crown that had been impacted. Crown damage was recorded if greater than 50% of the crown had been impacted (Han and Kellogg, 2000). Systematic sampling was chosen as it provides relatively consistent results which results in the lowest standard deviation (Han and Kellogg, 2000). Transect sampling was chosen over systematic plot sampling as the harvested openings are spaced equally apart therefore, it is possible that circular plots may return biased results.

To determine the utilization of cedar harvested from this site the mills the cedar was sold to were contacted and asked to provide a list of products they produced from this timber.

III. RESULTS AND DISCUSSION

Planning and layout

The costs for the layout of the harvest units was obtained from the contractor hired to complete the layout and from the UNBC researchers involved. The layout and planning costs were highest, $2.62/m^3, in the group selection because of the need to designate removal patches in the block (Table 3). In all ground based-treatments, recommended skidtrails were marked. The contractors were given the option to move these skid trails and to make them bladed skid trails.

In the group selection unit the primary goal of the layout crew was to design a skid trail system that would allow for multiple entries while promoting visual quality. Pre-existing landings from the construction of the East Twin Forest Service Road were utilized as an alternative to constructing new landings. The locations of these landings were suitable and resulted in decreased landing construction costs. As result of not having to designate remove patches and multiple skidtrails, the layout cost per cubic meter was lowest in the ground-based clearcut at $0.53/m^3. The cable-based clearcut incurred slightly higher costs ($0.68/m^3) due to increased time requirements for deflection line layout. Equipment selection for all treatments was left to the discretion of the contractors.

Table 3. Summary of layout and planning costs.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Traverse and boundary cost ($)	1095	232.75	1248.41
Deflection cost ($)	N/A	N/A	730
Mapping cost ($)	78.75	12.55	67.34
UNBC group selection layout cost ($)	750	N/A	N/A
Total cost ($)	1923.75	245.31	2045.74
Final volume (m^3)[a]	733.0	458.8	2987.9
Layout / planning cost ($/m^3)	2.62	0.53	0.68

[a] The final volume is the same as the net merchantable volume was calculated from the BC MOF Scale data.

Harvesting operations

Felling

Manual felling was the only method used for all harvest units because of large tree size (Avg. breast height diameter was >53.2cm) and steep slopes. Contractor A and B had separate fellers with similar amount of felling experience (20 years). The slope of the ground based treatments the slope ranged from 0 to 50% and on the cable treatment the slope ranged from 30 to 130%.

During felling, snow was present on the site but shovelling was not required for the majority of trees.

Increased butt flare in cedar in combination with butt rot can make directional felling difficult and at times dangerous. In all treatments the cedar was generally felled in a downhill direction as the trees were leaning and weighted by branches to fall in that direction. In the case of skidding and yarding it was preferred that the trees be felled downhill as the contractors stated it was easier and faster to choke or hook-up the tops of the trees than the butt. It was thought that breakage would be a concern when utilizing downhill felling and top choking/hooking, however from on site observations breakage occurred in less than 2.0% of the felled and skidded timber. In the partial cut trees were felled towards skid trails where tree conditions permitted. Where tree conditions did not permit the trees were felled in another safe direction or pushed over by the track skidder during skid trail construction.

Felling production from the cable clearcut is the highest as a result of the fastest cycle time of 1.97 minutes per tree (Table 4). This results in a volume production of 359.28m^3 per 8-hour shift at a cost of \$1.11/m^3. The second highest production occurred in the group selection. The group selection cycle time was lower than that of the ground-based clearcut even though directional felling was utilized. However, the higher volume per tree, 1.54m^3/tree for the ground-based portion of the clearcut versus 1.22m^3/ tree for the group selection treatment, resulted in a larger volume harvested in the ground-based clearcut per cycle. As a result the cost per cubic meter in the group selection and ground-based clearcut was minor with a difference of \$0.01 per cubic meter.

The results from this study indicate that total cycle time, tree size, and decay percentage can have a significant effect on the production. The volume per tree used to calculate the unit cost ($/m^3) was obtained from the BC Ministry of Forests (BCMOF) weigh scale data.

Table 4. Detailed time of felling phase.

	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)
Harvesting system	Ground-based				Cable	
Silvicultural treatment	Group selection		Clearcut		Clearcut	
Feller	A	A	A	A	B	B
Total productive time	1.864	59.6	1.983	55.4	1.29	65.5
Total non-productive time	1.265	40.4	1.596	44.6	0.681	34.5
Total cycle time	3.13	100	3.579	100	1.97	100
Gross volume per tree (m^3)	2.66		2.14		2.14	
Net. volume per tree (m^3)[a]	1.22		1.54		1.47	
Volume per hour (m^3/hr)	24.92		24.75		44.91	
Feller cost ($/hr)	50.00		50.00		50.00	
Felling cost ($/m^3)	2.01		2.02		1.11	

[a] The net merchantable volume per tree was calculated from the BC MOF Scale data.

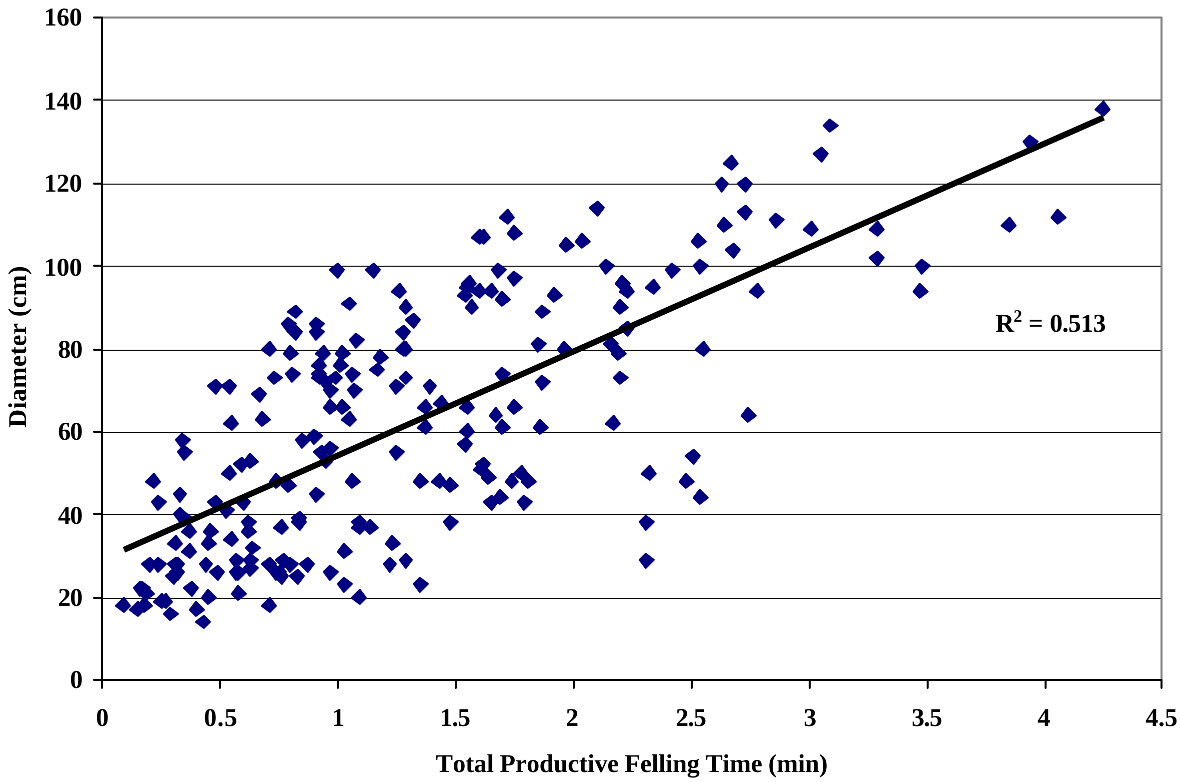
Equation 1 gives the delay free cycle time for manual felling for a cable-harvested unit, determined from a regression analysis. A significant linear relationship was found between cycle time and diameter. The equation is applicable for stand with similar characteristics and slopes of 0-60%.

[1] Total productive time (min) = 0.040 + 0.020 * Diameter

Sample number = 212 R^2 = 51.3% Standard error of estimate = 0.604

Figure 1 illustrates the relationship of felling productivity to the diameter.

Figure 1. Relationship between total productive time and diameter.



Primary transport

Skidding

Detailed skidding productivity for the John Deere 640 D line skidder is displayed in Table 5 for both treatments. A more complete summary of the skidding cycle elements is located in Appendix 2.

The skidder in the ground-based clearcut employed 5 chokers but 4 chokers were used in most cases. In the group selection, the operator employed 8 chokers, using 6 of them in the majority of instances, as he felt the bladed trails would allow for more wood to be hauled due to less obstruction from stumps and other remaining debris. He also felt that the longer travel time required more volume to be delivered to the landing in order to be financially viable. The timber in the group selection was also felled in a bunched matter allowing for more trees to be choked at once. The average skidding distance in the group selection was 284 m, which was 143 m longer than in the clear cut. As well, an additional 1.5 logs being delivered to the landing in the group selection each cycle resulted in a longer cycle time. The average total cycle time in the group selection was 2.83 minutes greater than the clearcut.

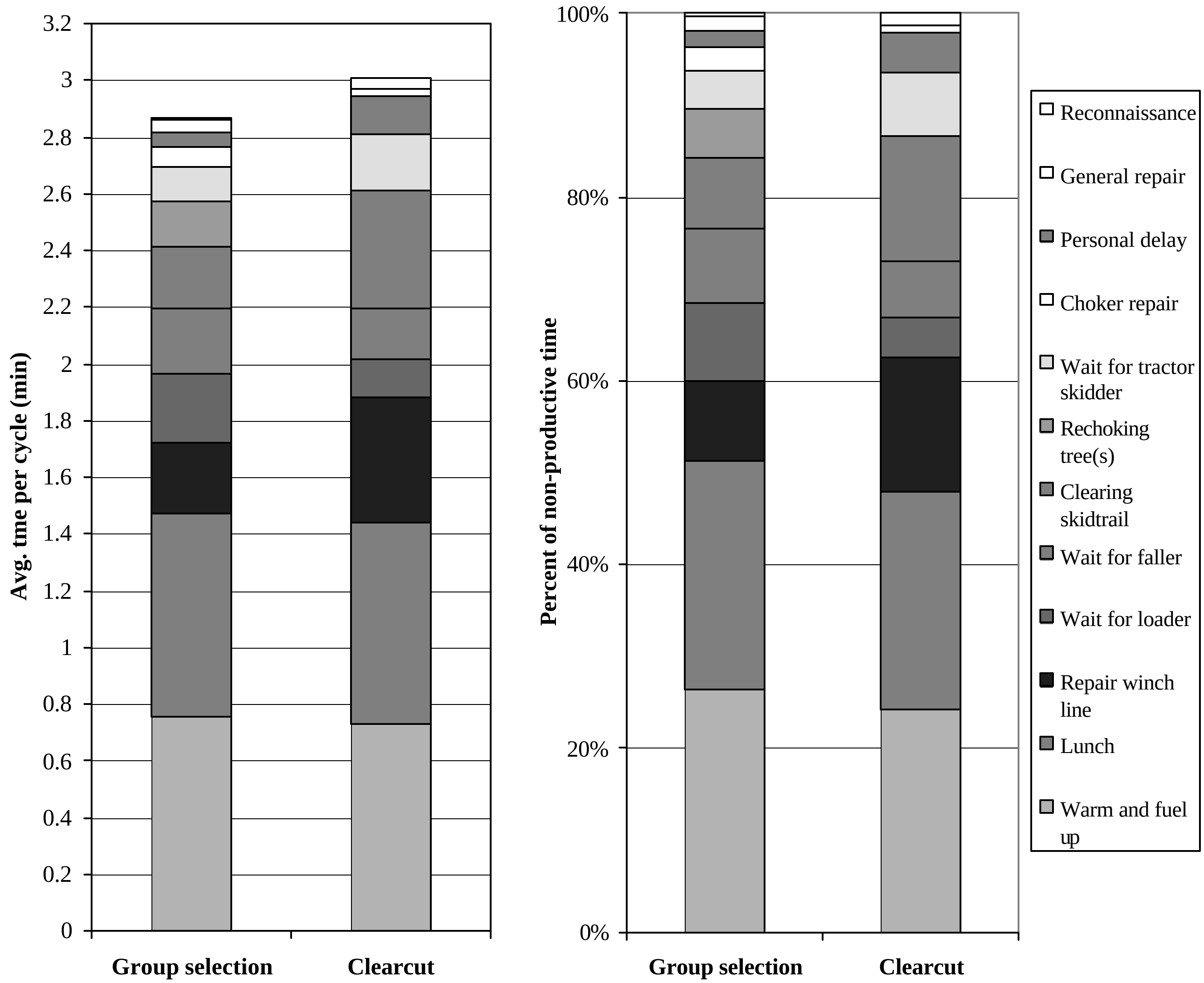
Table 5. Detailed time of ground-based skidding phase.

	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)
Treatment	Group selection		Clearcut	
Total productive time	18.47	86.55	15.50	83.74
Total non-productive	2.87	13.45	3.01	16.26
Total cycle time	21.34	100.00	18.51	100.00
Average distance (m)	238.7		140.8	
Average pieces/cycle (no.)	5.9		4.4	
Net. volume per tree (m^3)[a]	1.22		1.54	
Average volume/cycle (m^3)	7.13		6.69	
Volume per hour (m^3/hr)	20.05		21.69	
Skidder cost ($/hr)	89.74		89.74	
Skidding cost SMH ($/$m^3$)	4.48		4.14	

[a] The net merchantable volume per tree was calculated from the BC MOF Scale data.

Figure 2 illustrates the proportion each delay that constitutes the non-productive time. In the clearcut and group selection, 0.6% and 1.1% of the total cycle time was spent waiting for the track skidder (Caterpillar D6) to clear and develop skid trails. This could have been avoided through better planning by the contractor. In the group selection 7.7% of the non-productive time is due to waiting for the feller. This occurred because trees were felled into the same skid trail the line skidders were currently hauling from. In the clearcut, the skid trail clearing time was higher than the group selection. This is the result of having higher stump heights and greater slash accumulation present than in designated skid trails. In the group selection, chokers had to be replaced more often as the felled timber was often tangled or caught on trees and stumps, and as a result greater stress was placed upon the choker causing it to break. The slightly higher non-productive time in the group selection is partially the result of a 0.23-minute wait for the feller per cycle.

Figure 2. Summary of non-productive timing elements for skidding.



Equation 2 gives the total productive cycle time (delay free) for a rubber-tired line skidder, determined from a multiple regression analysis. A significant linear relationship was found between total productive time, treatment, distance, and number of logs. The equation is applicable for stand with similar characteristics and slopes of 0-30%

[2] Total productive time (min) = 8.582 - 1.195 * Treatment + 0.025 * Distance + 0.793 * No of logs

Sample number = 136 R^2 = 0.521 Standard error of estimate = 3.248

Where:
Treatment: 0 = Clearcut, 1 = Group selection

According to this equation the group selection treatment has a lower productive cycle time than the clearcut treatment when skidding the same distance with the same number of logs. In the context of the East Twin units the group selection had a higher productive cycle time, as the number of logs was greater on average by 1.5 pieces per turn. These additional pieces counteract the effect of the treatment constant. The number of logs also has a larger effect than distance on logging productivity.

Yarding

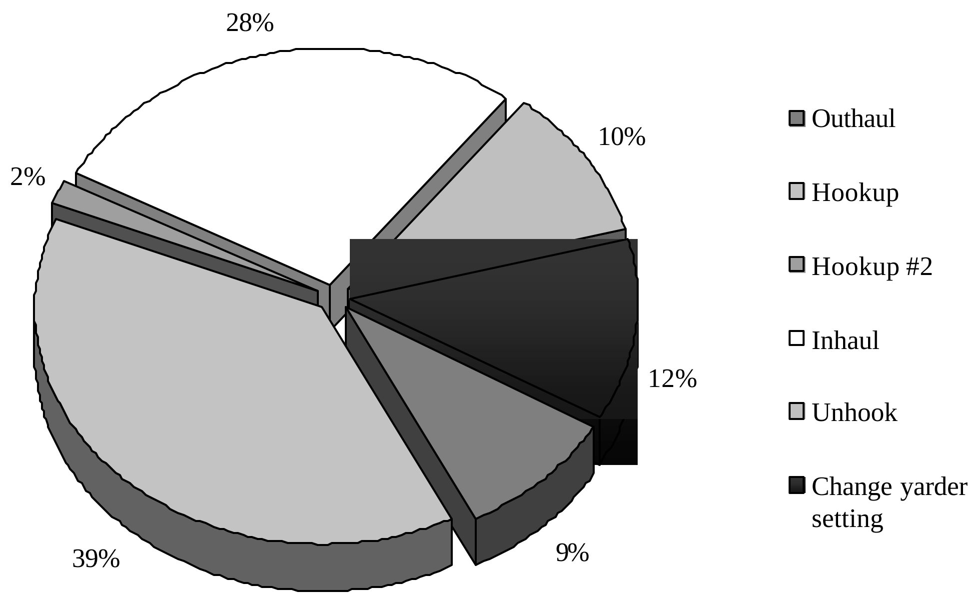
A Madill J7C tower yarder used an adapted running skyline system with a non-slackpulling carriage, with 5 chokers attached to it. The yarding was downhill with distances ranging from 35 to 225 meters with an average distance of 125 meters. Detailed timing data for this yarder is displayed in Table 6. The unit cost for yarding was \$7.73/ m^3, which is 72.5% more expensive than skidding in the group selection and 86.7% higher than skidding in the ground-based clearcut. . The yarding costs were considered extremely low in comparison to the rest of the province. This may be the result of the wages of the crew ranging from \$20 to \$25 per hour plus benefits where wages elsewhere in the province are on average $10 higher per hour plus benefits. The productive yarding time constitutes 75.05% of the total cycle time. This is higher than that found in the study by Pavel near Kitwanga, BC (1999), which found that only 55% of the total cycle time was actually productive. Yarder setting change time accounts for 11% of the total cycle time, which is 3% lower then in a FERIC skyline analysis (Bennett, 1997).

Table 6. Detailed timing summary of yarding cycle.

	Avg. time/element (min)	Time/cycle (%)
Total productive time	7.07	75.05
Yarder setting change time	1.01	10.72
Total non-productive time	1.34	14.23
Total cycle time	9.42	100
Pieces per cycle (no.)	2.59	
Volume per tree (m^3)	1.47	
Volume per cycle (m^3)	3.81	
Average yarding distance (m)	155.98	
Timed cycles (no.)	297	
Volume per hour (m^3/hr)	24.27	
Yarder cost ($/hr)	187.58	
Yarding cost ($/$m^3$)	7.73	

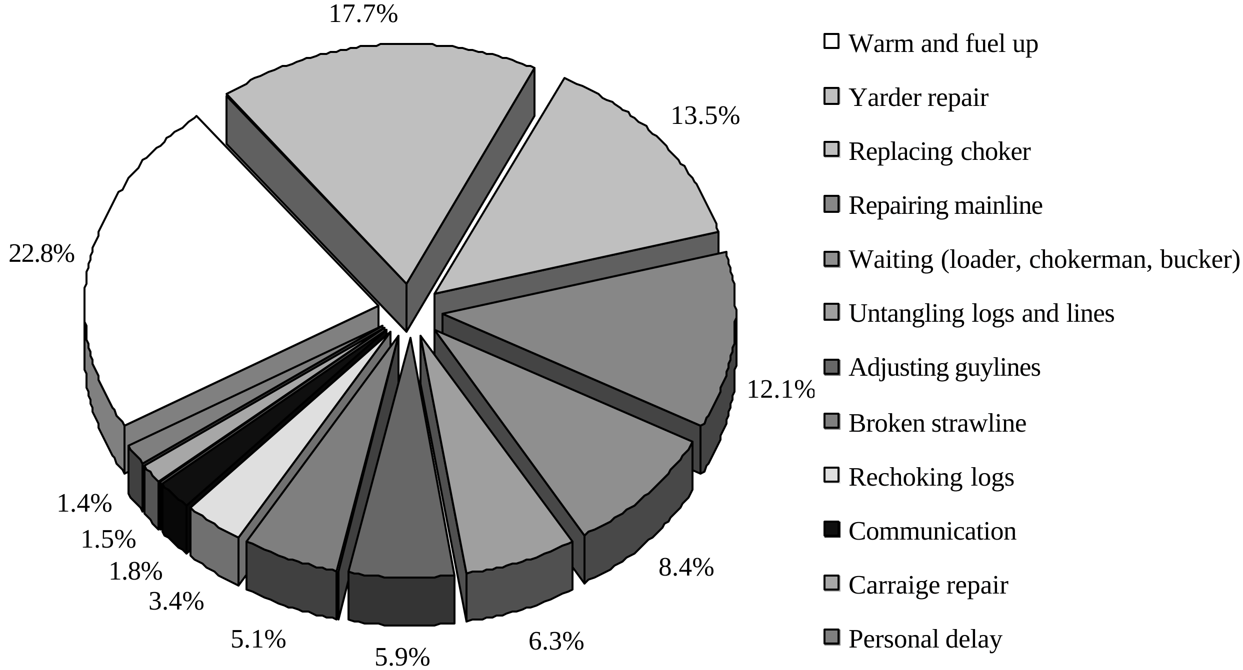
The hook up time was the most time consuming component, followed by the inhaul element (Figure 3). The hook up time was the most physically demanding portion of the yarding cycle. In order to hook up timber, the hook tenders on the hill must pull the chokers attached to the 250-kilogram non-slackpulling carriage toward the felled tree, often not only pulling the weight of the carriage and choker but also a portion of the yarding lines, mainline and haul back. There were five chokers attached to the carriage. Therefore during the hooking process, the hook tenders attempted to hook up to 5 trees, by repeating the hooking process. In most cases 2 chokers were utilized due to the distribution of felled trees. Yarding was accomplished by partially suspending the timber to avoid hanging up on the remaining stumps and slash. Partial suspension was accomplished by pulling the mainline in while the haulback line, which is slowly being released, has a brake applied to it. To maintain this lift, the yarder was not able to winch the lines at the same speed as during the outhaul process, where the carriage returns to the felled timber.

Figure 3. Productive cycle time distribution for cable yarding.



Approximately 19% of the non-productive time, or 2.52% of the total cycle time, was spent on repairing the haulback drum and general repairs, such as repairing a coolant leak or broken hydraulic line. Compared to a FERIC study by Dunham et al. (2000), this repair time was comparable. The time to replace chokers accounted for 13.5% of the non-productive time. The contractor stated that the supplier of the chokers was crediting the purchase price of the chokers as a result of the high breakage rate.

Figure 4. Non-productive cycle time distribution for cable yarding.



Equation 3 gives the total productive cycle time (delay free) for a single span, running skyline yarder, determined from a multiple regression analysis. A significant linear relationship was found between total productive time, distance, and number of logs. The equation is applicable for stand with similar characteristics and slopes of 0-130%

[3] Total productive time (min) = 2.002 + 0.027 * Distance + 0.639 * No of logs

Sample number = 285 R^2 = 29.0% Standard error of estimate = 1.791

As shown by the Equation 3, the number of logs has a greater effect on the total productive time than distance.

Processing / bucking

Processing for all sites was completed manually. The primary consideration of processing was to maximize commercially valuable wood recovery such as saw logs and post and rail wood. The saw logs were required to have a 10 cm shell, or distance between outer bark and inner rot, of timber in order to be merchantable. The minimum required length for saw logs was 5m to a maximum length of 19 m. These saw logs will be processed into small dimension aesthetic lumber. The post and rail timber required a 7.5 cm shell. Post and rail timber required a minimum length of 2.5m and a maximum length of 19m. The same bucker was used in both ground-based treatments, while Contractor B opted to buck the wood himself. Contractor B felt that by processing the wood himself, he could achieve the maximum commercial value from the timber.

The wood in the harvest units was uniform with approximately the same amount of butt and pocket rot, thus resulting in a high waste rate. The combined decay, waste, and breakage estimates for the ground-based group selection, ground-based clearcut, and cable clearcut treatments were 68%, 51%, and 52%, respectively. These numbers are high as a result of butt and pocket rot being present in the cedar. Butt and pocket rot not only destroy heartwood and sapwood, but also increases the possibility of breakage when felling and skidding/yarding. The decay level required the bucker to make multiple cuts at 0.75m intervals to determine where the timber was commercially valuable. In the cable clearcut, the timber was first processed for saw logs and then post and rail wood.

The site with the lowest cost was the ground-based clearcut; again this may be due to the lowest defect rate per tree and the higher proportion of spruce and subalpine fir (Table 7 and 8). The hemlock, spruce, and subalpine fir did not have any decay, thus was faster to process for the bucker. These species were processed for saw logs only.

Table 7. Shift level summary for bucking.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Bucker	A	A	B
Time (hrs)	45.25	18.75	138
Trees processed (no.)	603	316	2031
Volume per tree (m^3)	1.22	1.54	1.47
Cost ($/$m^3$)	1.54	0.96	1.15

In the cable block it was observed that the bucker was able to retrieve more commercial volume from cedar from the same stand of timber, by processing the wood for both saw logs and post and rail timber. This is illustrated in the final volume scale data; as the final volumes per tree of both clearcut treatments are very similar while the proportion per species varies (Table 8). In the group selection and ground-based clearcut, the timber was only processed for saw logs because of the lack of experience of Contractor A in processing defective cedar.

Table 8. Species volumes for each treatment.

	Volume (m^3)	% of total volume	Volume (m^3)	% of total volume	Volume (m^3)	% of total volume
	Ground-based				Cable	
Silvicultural treatment	Group selection		Clearcut		Clearcut	
Cedar	673	91.8	382.1	78.7	2793.6	93.5
Spruce and subalpine fir	60	8.2	103.7	21.3	76.5	2.6
Hemlock					117.8	3.9
Total	733	100	485.8	100	2987.9	100

Decking

Loading was not completed during or immediately after harvesting due to road restrictions. Therefore, the timber was not loaded onto trucks during harvesting, but instead decked on the landing. As a result the loading cost is the decking cost. Loading costs were the highest in the group selection because less skidded volume was available for the loader. The cable and ground-based clearcut both had lower costs. The cable clearcut had higher costs than the ground-based clearcut largely due to higher equipment costs per hour, although a heel-boom loader showed a greater productivity (m^3/hr) than it did in the group selection. The contractor chose a heel-boom loader, as it requires less operating space on the landing then a front-end loader. In this yarding operation landing area was minimal being only 45 by 45 meters.

Table 9. Shift level summary for loading.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Equipment	Front end log loader	Front end log loader	Heel-boom loader
Volume per tree (m^3)	1.22	1.54	1.47
Volume processed (m^3/hr)	16.20	25.91	21.65
Equipment rate ($/hr)	86.16	86.16	108.51
Cost ($/$m^3$)	5.32	3.33	5.01

Other harvesting costs

Equipment moving cost and skid trail and landing construction costs should be considered as part of the final cost. It was found that an average moving cost was $600 per low bed of equipment based upon a 35km round trip in the McBride area. Moving costs for the group selection and ground-based clearcut were shared according to volume removed from each treatment. In the cable clearcut block, a different contractor was involved in harvesting and thus new moving costs were incurred. The summary of moving costs was based on moving equipment from McBride to the harvest site, a 35km distance (Table 10).

Table 10. Summary of equipment moving costs.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Move in and out cost ($)	721.69	478.31	1200.00
Final net volume (m^3)	733.0	485.8	2987.9
Cost ($/$m^3$)	0.98	0.98	0.40

Skid trail and landing construction costs were calculated by timing the number of hours taken to construct the trail and landings, and the equipment and manpower used to complete the task for each treatment. The volume of timber removed from that treatment was then divided into the corresponding costs (Table 11). . The group selection did require 15 hours of landing and skid trail construction, the proportion of wood being extracted from that effort was lower than in the ground-based clearcut, where only 7.5 hours of landing and skid trail construction was required. This resulted in a higher cost per cubic meter in the group selection. As skid trail costs do not occur in the cable treatment and landings were pre-existing, from the ground based clearcut treatment, these results will not be included in the comparison of harvesting costs between treatments.

Table 11. Summary of skid trail and landing construction costs.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Time (hrs)	15	7.5	N/A
Equipment and manpower ($/hr)	145.09	145.09	145.09
Final volume (m^3)	733.0	485.8	2987.9
Cost ($/$m^3$)	2.97	2.24	N/A

Summary of harvesting costs

The unit cost ($\$/m^3$) was lowest in the ground-based clearcut treatment (Table 12). The ground-based clearcut had the lowest costs because of minimal layout and planning requirements, and a higher volume of merchantable timber extracted per tree. The layout and planning costs were highest, $\$2.62/m^3$, in the group selection because of the need to designate removal patches in the block. The cable-based clearcut incurred slightly higher costs ($\$0.68/m^3$) than the ground-based clearcut due to increased time requirements for deflection line layout. The increased volume is the result of more non-cedar species being present. These species have a lower low level of defect than the cedar. This lower defect level allowed the bucker to process the logs without making multiple cuts, thus increasing productivity. The cable clearcut treatment had the second lowest unit cost as the result of lower felling and moving costs. The lower felling costs were due to a shorter total felling cycle time and the lower moving costs were the result of a greater total volume being removed from the treatment. The group selection had the highest cost as a result of having the lowest merchantable volume per tree and long skidding distance. If the merchantable volume per tree of the group selection and ground-based clearcut was identical (1.54 m^3/tree) and the final volume of each treatment remained constant, the group selection harvesting system would cost $\$15.58/m^3$ due to decreases in felling and skidding costs. This is a decrease of $\$1.37/m^3$. The skidding distance in the group selection was nearly twice that of the ground-based clearcut. As a result of increased skidding distance, the skidding cycle time was 2.83 minutes greater. This resulted in the bucker and loader waiting for wood to process.

The results and discussion presented here were based upon relatively small treatment units ranging in size from 1.1 ha to 5.8 ha. According to the final volume data, the volume per ha is greater in the ground based clearcut treatment than in the other treatments due to a slightly lower defect percentage, 51% versus 52% in the cable clearcut and 68% in the group selection treatment. This defect variation results in a merchantable volume difference of $8.6m^3$/ha in the cable clearcut and 92.6m^3/ha in the group selection. This has a large effect on the harvesting costs. As a result of this higher volume, the ground-based clearcut has lower planning and layout, bucking, skidding, and loading costs than the group selection or cable clearcut.

Table 12. Summary of total costs. All costs are in \$/m^3.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Layout/planning cost	2.62	0.53	0.68
Felling cost	2.01	2.02	1.11
Skidding/yarding cost	4.48	4.14	7.73
Bucking cost	1.54	0.96	1.15
Loading cost	5.32	3.33	5.01
Moving cost	0.98	0.98	0.40
Total cost	16.95	11.96	16.08

Landing activity

According to the activity sampling, primary transportation was not delayed by loading and bucking on the landing (Table 13). In the ground-based treatments, the loader was waiting for timber to process 49% to 51% of the scheduled operating time. This was also similar for bucking where 39% to 41% of the scheduled operating time was spent waiting for timber to process. To improve loading and bucking efficiency on the landing in the ground-based treatments, another skidder may be employed to reduce the non-productive time. This may result in skidding delays unless an appropriate work plan is prepared. In the cable treatment, the operation was well balanced in its components, thus no improvements could be made on the landing.

Table 13. Summary of landing activity sampling

Element [a]	Time (min/hr)	% of time	Time (min/hr)	% of time	Time (min/hr)	% of time

Harvesting system		Ground-based				Cable	
Silvicultural treatment		Group selection		Clearcut		Clearcut	
	Delay	0.00	0.00	0.00	0.00	0.00	0.00
Skidder/yarder	Not on Landing	55.10	91.84	56.00	93.33	46.50	77.50
	Working	4.90	8.16	4.00	6.67	13.50	22.50
	Delayed from working	2.76	4.59	2.33	3.89	11.25	18.75
Loader	Waiting for timber	29.39	48.98	30.33	50.56	3.00	5.00
	Working	27.86	46.43	27.33	45.56	45.75	76.25
	Delayed from working	3.37	5.61	3.00	5.00	7.13	11.88
Bucker	Waiting for timber	23.57	39.29	24.67	41.11	5.63	9.38
	Refuelling and/or filing [b]	4.59	7.65	4.33	7.22	4.50	7.50
	Working	28.47	47.45	28.00	46.67	42.75	71.25

[a] Denotes if the equipment or personnel are delayed by another operation on the landing, working on the landing, not on the landing, and waiting for timber (no work available) on the landing.
[b] Saw refuelling and/or filing occurs off of the landing but limits buckers total productive time.

Stand damage

Following harvest, the all treatments were surveyed to determine the condition of residual trees. In the group selection treatment, the residual stand damage was classified by the type of damage and location from harvesting infrastructure (Table 13). It was found that 73% of the total damage occurred within 5 meters from the centre of a skid trail. The skid trail was a total of 5 meters wide. The remaining 27% of the damage occurred within 5 meters from the edge of harvest openings.

Table 14. Stand damage summary for group selection treatment.

Location	Damage		no injuries/ tree	Average size			Height [a] (cm)	Percent of total damage [b]			
	% of residual stand	% of total damage		Width (cm)	Length (cm)	Area (cm^2)		Stem	Stem and Root	Root	Crown
Skid Trails	6.75	73.0	1.41	14.0	42.1	659.4	66.2	84.2	13.2	2.6	0.0
Openings	2.50	27.0	1.10	9.5	18.7	578.3	12.6	90.9	9.1	0.0	0.0
Both	9.25	100.0	1.32	13.1	37.2	564.0	68.3	85.7	12.2	2.0	0.0

[a] Measured from base of tree to middle of damage
[b] Damage classes: Stem – Stem damage only, Stem and root – Stem and root damage combined, Root – Root damage only, and Crown – All crown damage.

Utilization of cedar

Cedar removed from the three treatments was sold as saw logs. This timber was sold to a mill in southern BC. The saw logs were processed into dimensional lumber such as 1" x 4"'s, 2" x 3", and 2" x 12" of various lengths, radius edge decking, tongue & groove, channel siding, and rough facia board. The mill also stated that they would cut other products depending on customer requests. Post and rail timber was sold locally from the cable treatment only. This was the result of the experience of Contractor B in processing defective cedar compared to that of Contractor A. The post and rail timber was processed into 3"x3" and 4"x4" posts of 8 to 10 foot lengths and 4"x4" and 3"x3" rails of 8 to 16 foot lengths. These are products that the cedar may have been turned into and are not all of the possible products that could be made if the cedar was milled differently.

IV. CONCLUSION

In 1997, the UNBC and BCMOF Robson Valley District initiated the Northern Rockies Wet-belt ICH/ESSF Silvicultural Systems Project, to investigate the effects of partial cut/clearcut prescriptions on ecosystems dynamics in ESSF and ICH stands in the northern portion of the interior wet belt, in central British Columbia. This report covers the final results of harvesting cost study for the first harvested site, East Twin. East Twin contained three treatments, ground-based clearcut, cable based clearcut, and ground-based group selection. UNBC objective was to assess planning, productivities and cost; stand damage, and soil disturbance; and identify ways to improve operational planning and implementation of both partial and clearcut harvesting operations.

The group selection prescription clearly required more intensive planning and layout, requiring 4.9 and 3.8 times more planning and layout investment than the ground-based and cable clearcut treatments respectively. Felling on the other hand was more cost efficient in the cable clearcut due to the total cycle time being 1.6 to 1.8 times lower than in the group selection and ground-based clearcut respectively. The greater merchantable volume per tree in the ground-based clearcut results in similar felling costs per cubic meter as in the group selection treatment. As a result of the increased volume per tree, skidding cost was lowest in the ground-based clearcut at $\$4.14/m^3$ followed closely by the group selection at $\$4.48/m^3$. Yarding costs were $\$7.73/m^3$, which is considered extremely low. This may be the result of the wages of the crew ranging from $20 to $25 per hour plus benefits where wages elsewhere in the province are on average $10 higher plus benefits. The greater merchantable volume per tree in the ground-based clearcut also resulted in a lower bucking and loading costs compared to that in the cable clearcut and group selection treatments.

Loading cost was the highest in the group selection due to increased non-productive time while waiting for the skidder, as it had to travel on average twice as far as in the ground-based clearcut, an additional 143m. Move-in and-out costs were a flat rate for all contractors, thus the cost per cubic meter depended largely on the volume removed. It was suggested that adjacent harvest units be packaged together in sales to minimize this cost. Overall the cost per cubic meter was lowest in the ground-based clearcut treatment. The cable clearcut total cost was lower than expected at $16.08/m^3$, which was due to efficient harvesting practices, and low labour costs. As previously mentioned, this resulted from the lower felling, moving costs, and low yarding costs. Tree volume, defect, and efficiency of harvesting elements were the most important factors affecting a final cost.

The bucking and loading processes according to the landing activity sampling did not delay skidding or yarding in all three treatments. As previously mentioned another skidder being used could improve the loading and bucking efficiency in the ground-based treatments. In the cable treatment the yarder kept the loader and bucker productive.

Stand damage levels in the group selection is 9.25% of the residual stand. Of this damage 73% is located along skid trails and could be decreased if prevention or remediation techniques were utilized.

Opportunity costs, non-timber values, and long-term costs, aspects not measured in this report, should be considered when comparing costs and productivities of partial and clearcuts. Economic feasibility in all three treatment units is dependent on market value. The result from this study are derived from western red cedar dominate stands in the ICHwk3 biogeoclimatic zone of the Robson Valley Forest District and should only be extrapolated to similar sites.

V. RECOMENDATIONS

As non-timber values and social values increase, both conventional and alternative harvesting practices will have to become more economically efficient and environmentally responsive. In old growth cedar in the McBride area where large diameter trees with high defect rates exist, the following are recommendations for improving the partial and clearcut logging operations in ICH stands, based on our study:

1. Layout of harvest groups should be arranged in a manner that facilitates felling the trees into an open skid trail or other opening in a group selection treatment, as it is easier for the feller. Be sure to examine the trees to be removed for lean and branch orientation, as it will affect the direction and ease of felling.
2. In a cable harvesting system, ensure adequate yarding deflection from proposed yarder landing locations exists, during the layout phase, as it will ensure that all of the timber scheduled for removal will be harvested, and lower the chance of any possible yarding complications and thus costs.
3. Straight skid trails should be used. Small radius curves in skid trails cause skidded wood to swing into residual trees, wounding trees next to the trails.
4. Leave low stumps. High stumps on skid trials can force the skidded timber to one side, wounding tree next to the trial. High stumps can also cause skidding hang-ups.
5. Before harvesting ensure that a buyer exists for the wood being harvested and that the highest commercial volume is being extracted from the timber by processing for the use of multiple products (i.e. saw logs and post and rail).

6. Ensure no unnecessary non-productive delays by developing work plans at the beginning of each shift. An example would be ensuring that the feller and skidders are not working so close to one another that they negatively impact each other's production.
7. Mitigate stand damage. As this site may be used for recreational purposes, damaged trees should be removed as they are more susceptible to decay and thus windthrow or wind snap. This will ensure public safety and minimize the loss of timber from wound origin decay. Trees on designated skid trails that are damaged should either be removed after the harvesting of openings or adequate prevention steps should be taken before hand. These include the use of artificial tree protection rigging such as rub pads.

IV. FUTURE RESEARCH

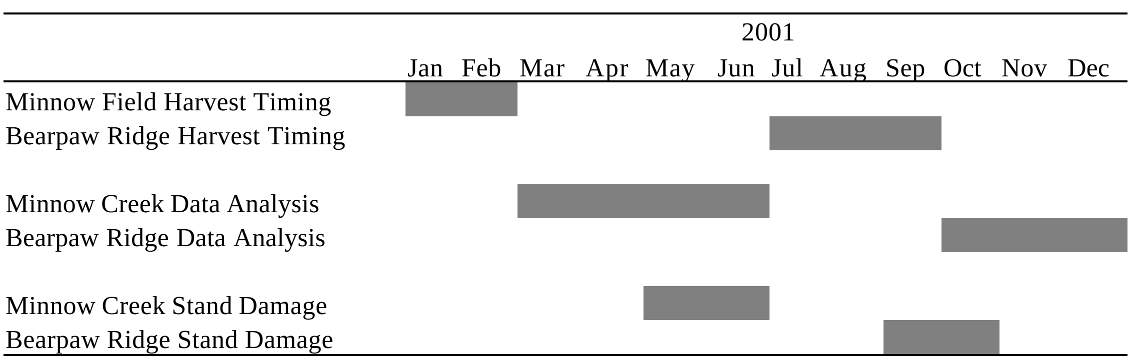
The next ICH site is located at Minnow Creek, an ICH ground based site, located 35 km west of McBride, BC in East Central BC. The Minnow Creek site (TSL A61746) in Robson Valley was completed on February 15th, 2001. Analysis of these results will begin when weight scale data is available for the site in mid March. The final site is a helicopter block in the Prince George District on Bearpaw Ridge, located on the eastern rim of the central Interior Plateau between Purden Lake and McBride, BC. It is in the ESSF biogeoclimatic zone and is located at an elevation of roughly 1200 m. Canfor, our industrial partner for this site is committed to this project and interest to seeing it to completion in 2001. The stand is composed of uneven-aged timber and is being harvested as a partial cut, as it is located in habitat designated as "caribou medium". The treatments are singletree selection, group selection (1 ha in size) and group selection (0.25 ha in size).

Once field data collection is completed a regression model, to predict productivity, will be developed using data from all sites. Table 15 summarises the future research sites and Figure 5 outlines the timeline for these studies.

Table 15. Summary of future research study areas.

Study Area Name	License #	Treatment Type	Area of Treatment (ha.)	Size of Internal Harvest Groups / Leave Patches	Estimated Schedule	Harvesting System
Bearpaw Ridge	CP 17E, TFL 30	Single-tree Selection (30% removal)	25.5	Single-tree to small (2-~10 tree clumps)	Harvesting Commencing Mid July to Mid September, 2001	Aerial (Helicopter)
		Small-group Selection (30% removal)	29.0	Average 0.25 ha openings, some +/-		
		1-ha. Clearcuts (30% removal)	59.2	About 1.0 ha. each		
Minnow Creek	TSL A61746	Group Selection (30% Removal)	11.2	0.1-0.3 ha. harvest groups; average 0.2 ha	Harvested January 2 to February 15, 2001	Conventional ground-based system
		Group Retention (70% Removal)	10.7	0.1-0.3 ha. leave patches; average 0.2 ha		
		Clearcut (100% Removal)	7.4	N / A		

Figure 5. Timeline for future research



VI. REFERENCES

Bennett D.M. (1997) Partial cutting in mountainous old-growth forests in coastal British Columbia; harvesting productivity and cost, and residual stand impacts. FERIC Publication TR -119. 20 pp.

Dunham M. and Gillies, C. (2000) Skyline partial cutting in the Interior Cedar-Hemlock biogeoclimatic zone: harvesting productivity and cost. FERIC Publication, Advantage Vol 1. No 40. 16pp.

Han H-S. and Kellogg L.D. (2000) A comparison of sampling methods for measuring residual stand damage from commercial thinning. Journal of Forest Engineering. ISSN 0843-5243 Vol. 11 No. 1 63-71pp.

Olsen, E.D. and Kellogg L.D. (1983) Comparison of time-study techniques for evaluating logging production. Forest Research Lab. Oregon State University. Corvallis, Oregon. Research Paper 1701. 4p.

Pavel, M. (1999) Analysis of a Skyline Partial Cutting in the Interior Cedar-Hemlock Biogeoclimatic Zone. FERIC Publication TR-125. 21 pp.

Thibodeau, E. D., Krag, R. K., and I.B. Hedin (1996) The Date Creek Study: Productivity of ground-based harvesting systems in the interior cedar hemlock zone of British Columbia. FERIC Publication SR-114. 38 pp.

APPENDIX 1. MACHINE COST

CONTRACTOR		A			B
OWNERSHIP COSTS	John Deere 640G Line Skidder	Caterpillar D6R Line Skidder	John Deere 644H Front End Log Loader	Madill 172-5 Drum Tower Yarder	Barko 475B Heel Boom Loader
Total Purchase Price (P) $	246,200	395,000	316,000	900,000[a]	544,000
Expected Life (Y) y	5	5	5	10	5
Expected Life (H) h	10000	10000	10000	20000	10000
Scheduled hours/year (h)=(H/Y) h	2000	2000	2000	2000	2000
Salvage value as % of P (s) %	30	30	30	30	30
Interest rate (Int) %	10	10	10	10	10
Insurance rate (Ins) %	3	3	3	3	3
Salvage value (S)=(P*s)/100) $	73,860	118,500	94,800	270,000	163,200
Average investment (AVI)=((P+S)/2) $	160,030	138,250	110,600	315,000	190,400
Loss in resale value ((P-S)/H) $/h	17.23	27.65	22.12	31.50	38.08
Interest ((Int*AVI)/h) $/h	8.00	6.91	5.53	15.75	9.52
Insurance ((Ins*AVI)/h) $/h	2.40	2.07	1.66	4.73	2.86
Total ownership costs (OW) $/h	27.64	36.64	29.31	51.98	50.46
OPERATING COSTS					
Wire rope (wc) $				15100	
Wire rope life (wh) h				2000	
Rigging and radio (rc)				13800	
Rigging and radio life (rh) h				4000	
Fuel Consumption Diesel (F) L/h	22	23	22	40	20
Fuel Cost Diesel (fc) $/L	0.50	0.50	0.50	0.50	0.50
Lube and oil as % of fuel (fp) %	15	15	15	15	15
Track and undercarriage replacement (Tc) $	0.00	20000	0	10000	8,000
Track and undercarriage life (Th) h	0.00	10000	0	100000	10,000
Annual repair & maintenance (Rp) $	20,000	14000	12000	20,000	20,000
Annual operating supplies (Oc) $	1,500	1500	1000	1,500	1,000
Annual tire consumption (t) no.	2		2		
Tire replacement (tc) $	3,300		2300		
Operator wages $/h	25.00	25.00	25.00	25.00	25.00
Hook tender wages				20.00	
Number of hook tenders				2	
Wage benefit loading (WBL) %	35	35	35	35	35
Shift length (sl) h	8	8	8	8	8
Wire rope (wc/wh) $/h				7.55	
Rigging and radio (rc/rh) $/h				3.45	
Fuel (F*fc) $/h	11.00	11.50	11.00	20.00	10.00
Lube and oil ((fp/100*(F*fc)) $/h	3.30	3.45	3.30	6.00	3.00
Tires ((tc*t)/h) $/h	3.30		2.30		
Repair and maintenance (Rp/h) $/h	10.00	7.00	6.00	10.00	10.00
Track and Undercarriage (Tc/Th) $/h		2		0.10	0.80
Operating supplies (Oc/h) $/h	0.75	0.75	0.50	0.75	0.50
Wages and benefits (W*(1+WBL/100) $/h	33.75	33.75	33.75	87.75	33.75
Prorated overtime ((1.5*W-W)*(sl-8)*(1 +WBL/100))/sl) $/h	0.00	0.00	0.00	0.00	0.00
Total operating costs (OP) $/h	62.10	58.45	56.85	135.60	58.05
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	89.74	95.09	86.16	187.58	108.51

[a] Yarder cost includes the cost for a non-slackpulling carriage.

* Wage Costing: Feller is on a day rate of $400 based on an 8-hour workday and the bucker is on an hourly rate of $25 per hour

APPENDIX 2 Detailed time of felling phase

	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)
Treatment	Group Selection (70% retention)		Clearcut Ground-based		Clearcut Cable	
Feller	A	A	A	A	B	B
Productive Elements:						
Moving from tree to tree	0.302	9.6	0.359	10.0	0.367	18.6
Brushing	0.065	2.1	0.096	2.7	0.076	3.8
Cutting	1.192	38.1	1.175	32.8	0.799	40.6
Wedging	0.086	2.7	0.112	3.1	0.012	0.6
Bucking	0.021	0.7	0.015	0.4	0.000	0.0
Shovelling	0.165	5.3	0.183	5.1	0.019	0.9
Reconnaissance	0.034	1.1	0.043	1.2	0.018	0.9
Total Productive Time	1.864	59.6	1.983	55.4	1.290	65.5
Non Productive Elements						
Resting	0.570	18.2	0.510	14.2	0.403	20.5
Fuelling saw	0.102	3.3	0.123	3.4	0.079	4.0
Filing saw	0.054	1.7	0.019	0.5	0.088	4.5
Fixing saw	0.021	0.7	0.148	4.1	0.099	5.0
Moving equipment and fuel	0.001	0.0	0.061	1.7	0.011	0.6
Hiking in block	0.067	2.1	0.056	1.6	0.000	0.0
Choking trees	0.043	1.4	0.302	8.4	0.000	0.0
Waiting for skidder	0.039	1.2	0.140	3.9	0.000	0.0
Lunch	0.368	11.8	0.238	6.6	0.000	0.0
Total Non-Productive Time	1.265	40.4	1.596	44.6	0.681	34.5
Total Cycle Time	3.130	100.0	3.579	100.0	1.970	100.0
Volume per hour (m^3/hr)	24.92		24.75		44.91	
Feller cost ($/hr)	50.00		50.00		50.00	
Felling cost ($/$m^3$)	2.01		2.02		1.11	

APPENDIX 3 Detailed time of ground-based skidding phase

	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)
Treatment	Group Selection (70% retention)		Clearcut Ground-based	
Productive Cycle Elements				
Travel empty	3.51	16.43	2.74	14.81
Winch line out	0.90	4.22	0.69	3.71
Winch line in	0.72	3.37	0.60	3.24
Repositioning	0.15	0.69	0.07	0.40
Choke #1	2.86	13.40	2.42	13.08
Choke #2	1.62	7.57	1.46	7.91
Choke #3	0.70	3.26	0.59	3.21
Choke #4	0.39	1.83	0.18	0.95
Choke #5	0.08	0.37	0.00	0.00
Total choking time	5.64	26.42	4.65	25.15
Travel Loaded	4.38	20.51	4.29	23.21
Unchoking	1.35	6.34	1.13	6.08
Delimbing	0.30	1.41	1.32	7.14
Turning on landing	1.53	7.16		
Total Productive Time	18.47	86.55	15.50	83.74
Total Non-productive	2.87	13.45	3.01	16.26
Total Cycle Time	21.34	100.00	18.50	16.26
Average distance (m)	238.70		140.80	
Number of chokers available	8		5	
Choking averages				
Trees in choke #1/cycle (no.)	2.90		2.40	
Trees in choke #2/cycle (no.)	1.70		1.10	
Trees in choke #3/cycle (no.)	0.90		0.50	
Trees in choke #4/cycle (no.)	0.30		0.30	
Trees in choke #5/cycle (no.)	0.10		0.00	
Average pieces/cycle (no.)	5.90		4.40	
Volume per hour (m3/hr)	20.05		21.69	
Skidder cost ($/hr)	89.74		89.74	
Skidding cost ($/m3)	4.48		4.14	

APPENDIX 4 DETAILED TIME OF YARDING PHASE

	Avg. time/element (min)	Time/Cycle (%)		Avg. time/element (min)	Time/Cycle (%)
Productive Cycle Elements			**Non-productive Elements**		
Outhaul	0.735	7.80	Warm and fuel up	3.25	3.36
Hookup	3.131	33.22	Replacing choker	1.92	1.98
Hookup #2	0.128	1.35	Repairing mainline	1.73	1.78
Inhaul	2.246	23.83	General repairs	1.19	1.23
Unhook	0.838	8.89	Adjusting guylines	0.84	0.87
			Wait for loader	0.83	0.86
Total productive time	7.076	75.10	Repairing haulback drum	0.79	0.82
			Broken strawline	0.72	0.74
Yarder setting change time	1.006	10.68	Adjusting haulback brake	0.53	0.55
			Tangled lines	0.52	0.53
			Rechoking log	0.49	0.50
			Untangling logs	0.33	0.34
			Wait for chokerman	0.31	0.32
			Communication	0.26	0.26
			Repairing carriage	0.21	0.22
			Personal delay	0.20	0.21
			Crossed lines	0.05	0.05
			Wait for bucker	0.04	0.04
			Wait for chaser	0.01	0.01
			Total non-productive time	1.34	14.22
Total cycle time (min)	9.42	100.00			
Cycles per hour (no.)	6.37				
Average pieces/cycle (no.)	2.59				
Average yarding distance (m)	155.98				
No. of timed cycles		297			
Total harvested volume (m^3)		2987.9			
Total trees (no.)		2031			
Volume per tree (m^3)		1.47			
Volume per hour (m^3/hr)		24.27			
Yarder cost ($/hr)	187.58				
Yarding cost ($/$m^3$)	7.73				