A Comparison of Partial Cut and Clearcut Harvesting Productivity and Cost in Old Cedar-Hemlock Forests in East Central British Columbia

Chad Renzie

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ABSTRACT

Although clearcutting has been a historically dominant harvesting method in British Columbia (representing 95% of the total volume harvested annually), forest managers are increasingly recommending the use of alternative silvicultural systems and harvest methods, including various types of partial cutting, to meet ecological and social objectives. In this study we compared harvesting productivity and costs between treatments in 300-350 year-old Interior Cedar-Hemlock stands. This was achieved through detailed and shift level time studies. Residual stand damage was also assessed and recommendations for improving operational planning/layout and the implementation of clearcut and partial cutting silvicultural prescriptions were made. Harvesting costs varied in the ground-based clearcut treatments from $\$10.95/m^3$ - $\$15.96/m^3$ and $\$16.09/m^3$ - $\$16.93/m^3$ in the group selection treatments. The ground-based group retention treatment had a cost of $\$13.39/m^3$, while the cable clearcut had a cost of $\$15.70/m^3$. An understanding of the traditional and alternative products that can be derived from the harvested timber was imperative to increasing the amount of merchantable volume and reducing the corresponding harvesting costs. Stand damage was greatest in the group selection treatments; however mechanized felling showed an increase in stand damage over manual felling while grapple skidding showed a decrease in skidding damage compared to line skidding.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1 Introduction

In the past, forest management in coastal and interior cedar hemlock forests stands tend to focus on the conversion of forests to even-aged second-growth forests through clearcut harvesting. However, forest resource managers have begun to prescribe a wide range of stand structures, age structures, and species compositions, to meet an increasing array of ecological, social, and silvicultural objectives (Weetman, 1996; Arnott and Beese, 1997; Kohm and Franklin, 1997; Jull et al., 1998). These include various silvicultural strategies, from smaller openings, dispersed partial cuts, and variable retention systems. Managing for non-timber resources is especially important in the Columbia trench between Prince George and McBride, British Columbia (BC), because of the pressure to preserve mountain caribou (*Rangifer tarandus-caribou* (Linnaeus)) habitat and a tourism industry (Jull et al., 2002, Moon et al., 2004). Improved knowledge regarding the implementation of alternative silvicultural methods is imperative to meet these demands, including productivity and cost.

The costs involved with various alternative silvicultural methods in western red cedar (*Thuja plicata* Donn ex D. Don) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) forests, specifically the interior cedar hemlock (ICH) stands, in BC are poorly understood. There is limited knowledge on harvest productivity and cost in partial cutting these stands is due to the low market value of the ICH stands during the early 1980's (Mandzak et al., 1983; Sinclair, 1984) and the perception that only clearcut harvesting was financially viable. The Northern Rockies ICH/Silvicultural Systems Project was established to examine ways of managing ICH forests in a manner that would address both ecological and socio-economic concerns (Jull et al., 2002). This project investigates the effects of various partial cutting regimes on short-term and long-term stand growth and development, loss and creation of stand structural biodiversity attributes (wildlife trees and course woody debris), windthrow, regeneration, and tree mortality. The research projects address a wide variety of issues including: 1) short-term and long-term growing stock development, stand productivity, stand structural development, species composition, logging and wind damage and mortality; and 2) short-term and long-term processes of loss and creation of structural biodiversity attributes, specifically wildlife trees and coarse woody debris. As part of this study, a harvesting productivity and cost analysis of partial cutting versus clearcutting was conducted, this complements the long term goals by providing an economic and operational perspective. A harvesting research team at the University of Northern British Columbia (UNBC) in cooperation with the Ministry of Forests Small Business Enterprise Forestry Program monitored harvesting activities in the two study sites: East Twin and Minnow Creek, located near McBride, BC.

Although literature about partial cutting, any silvicultural system that remove selected trees and leave desirable trees for various stand objectives, is abundant for coastal BC (Moore, 1991; Daigle, 1995; Bennett, 1997), past research efforts concerning the costs of partial cutting of ICH stands in central BC have been minimal. The forest management objectives, stand structures, harvesting conditions in the interior BC are quite different from those of coastal BC.

In a second growth cedar hemlock stand near Kispiox, BC, it was found that the cost of a conventional harvesting system in a partial cut was 1.98 times higher than that of a conventional clearcut (Thibodeau et al., 1996). Two studies in old growth ICH stands near Revelstoke (BC), found that harvesting costs to be 1.1 to 1.4 times higher than that of a clearcut (Walters, 1997a; Walters, 2001). A cable skyline system partial cut in a cedar dominant stand in east central BC, costs 3.77 times higher than a conventional ground-based clearcut (Pavel, 1999).

2 Objectives

The broad goal of this study was to determine the production rates, costs, and residual stand damage of partial harvesting systems in ICH stands. Improved knowledge regarding the costs of implementing alternative silvicultural methods is imperative for forest managers to meet non-timber values of the area while meeting the demand for cedar products. This study was done for three different levels of tree removal treatments in the ICH. The specific objectives are:

1. Determine planning/layout cost for partial cut and clearcut blocks;
2. Compare production rates (m^3/hr) and cost (\$/m^3) for various silvicultural prescriptions using ground-based and cable harvesting systems;
3. Derive harvest production prediction models based on appropriate independent variables; and
4. Quantify residual stand damage for the different partial cutting prescription blocks.

3 Literature Review

3.1 Planning and Layout

Planning and layout in timber harvesting operations is key to the success of an efficient harvesting operation and reduces environmental impacts. The layout costs in group selection and retention units for interior cedar dominant stands are 1.9 to 4 times that of clearcut units (Thibodeau et al., 1996; Walters, 1996; Walters, 1997a; Walters, 2001). This is similar to other interior forest types in Canada and the United States where partial cut layout costs ranged from 2.4 to 6.3 times that of clearcut units (Kellogg et al., 1991; Kellogg et al., 1996; Dunham, 2001, 2004; Sambo, 2003). This higher cost of partial cutting than clearcutting is the result of more intensive timber cruising, the creation of internal patch cut layout boundaries, increased tree marking, and the need for designed skid trail networks through the residual stand that allows for multiple entries (Thibodeau et al., 1996; Walters, 1996; Walters, 1997a; Walters, 2001).

Harvest design plans consider many factors including the optimal spacing of yarding corridors, haul roads, skid trails, and landings (Pavel, 1999). Optimal spacing models determine the best spacing based upon equipment and stand characteristics (McNeel and Young, 1994; Howard et al., 1996; Rutherford, 1996). While cost savings may be achieved through optimal spacing, the benefits must be compared with the impacts on the other management goals (Pavel, 1999). Regardless of optimal spacing, in ground-based units, the orientation of openings and extraction network should be designed and oriented to facilitate enhanced felling and skidding productivity. Patch openings should be designed to “funnel” trees in the direction of the skid trail. This funnelling can result in improved skidding /

yarding and felling productivity while reducing residual stand damage (Bennett, 1993; Thibodeau et al., 1996; Kosicki, 2000a).

Timber cruising for partial cut units is time consuming because of the required two-measure plots per hectare versus one measure-plot and one count-plot per hectare in clearcut units (BC Ministry Forests, 1996a). This requirement increases layout cost, but high quality field layout is regarded as crucial to an efficient partial cutting operation and as a result should remain a high priority (Bruno, 1979; Hedin, 1994; Thibodeau et al., 1996).

Tree marking increases layout costs though allows fellers to be free from selecting trees to be felled, thus increasing their productivity (Kemmler, 2000). Marking reflects the objectives set for the logging operation and establishes the height, species, and stand structure of the remaining stand. Where directional felling is required and feasible, it is recommended that the directions to be and not to be felled be marked on the tree (Aho et al., 1983; Moore, 1991). Tree marking must consider the safety of the feller through a knowledge of characteristics (i.e., lean, and distribution of branches) of individual and adjacent trees (Moore, 1991; Walters, 1997a).

3.2 Felling

In both partial and clearcut harvesting, felling by mechanical means in the ICH in east central BC resulted in cost savings from 40 to 50% compared to manual felling (Thibodeau et al., 1996). Mechanical felling has a proportionally higher production rate (m^3/hour) over increased ownership and operating costs. Besides cost, advantages of mechanized felling compared to manual felling include better worker safety, better control of stems to reduce breakage and residual tree damage and improved skidding efficiency through tree bunching (Kluender and Stokes, 1994; Thibodeau et al., 1996; Parker, 2002). Advantages of manual felling include no constraints on slope and tree sizes. However, when felling trees using a chainsaw, stumps should be close to the ground and on an angle to minimize hang-ups (Pavel, 1999; Han and Renzie, 2005).

Where manual felling is required, the primary concern of the feller must be safety (Moore, 1991; Parker, 2002). The feller must take into consideration the kick back potential of the chainsaw, assess the trees for possible hazards (i.e., loose branches that may dislodge when falling), and have an escape route ready in case the tree does not fall as planned. Felling productivity is also affected by environmental conditions. In colder climates, felling efficiency declines because the wood becomes harder to cut when it is frozen (Mitchell, 2000).

The manual felling costs in 60% volume removal treatments (group retention) in the ICH are 1.2 times more expensive than those in clearcuts as the result of directional felling requirements (Thibodeau et al., 1996). While treatment can affect the felling cost, merchantable volume per stem often has a larger effect on the total cost (Ashe, 1916; Lynford, 1934; Mann and Mifflin, 1979; Kluender et al., 1997).

3.3 Primary Transportation

3.3.1 Skidding

The use of medium sized line and grapple skidders, commonly used for conventional or mechanized harvests of clearcuts, in heavy removal partial cut operations is both cost effective and efficient (Thibodeau et al., 1996). The use of horses, small crawler tractors and/or harvester/forwarder systems were recommended for light removal partial cut systems, as these machines or animals are easy to maneuver. Tree size and felling method may also dictate skidding equipment and methods, in the case of large tree sizes where mechanical felling may not be possible. Mechanical felling allows for the bunching of logs, making the use of grapple skidders economically viable. When bunching is not possible, logs may be more efficiently removed by a line skidder (Kluender and Stokes, 1994; Thibodeau et al., 1996). The use of line skidders may be economical in a small scale operation at a lower production rate as a lower capital investment is required compared to grapple skidders (Kluender and Stokes, 1994). In addition, the use of line skidders promotes manual felling, also reducing overall capital investment. The skidding cost per cubic meter, when using a line skidder, in a 60 % removal treatment (group retention) is 1.85 times higher than a clearcut (Thibodeau et al., 1996). The differences observed in costs are often due to increased skidding cycle time, as much as 6%, in partial cut treatments compared to similar clearcut units (Krag, 1992). Skidding productivity is also affected by weather, skidding distance and slope (Mitchell, 2000). In a uniform stand, the greater the slope and skidding distance, the less productive the skidder becomes as the cycle time to retrieve a turn of logs increases while the volume of the turn remains fairly constant.

3.3.2 Cable Yarding

Uphill yarding is most efficient when yarders with slack-pulling carriages and chokers are utilized in either a single or multi-span skyline system (MacDonald, 1999). For downhill yarding, a running skyline system is required as the haulback line allows for the carriage to return uphill and provides better control of the carriage and payload when traveling downhill (Gardner, 1980; Bennett, 1997; MacDonald, 1999; Dunham and Gillies, 2000). While a running skyline system can be used in partial cuts, it is more popular in clearcuts and often is used with a mobile backspar. Advantages of single span systems in both partial and clearcuts are generally limited to higher production and thus reduces costs due to lower yarding corridor change times (Howard et al, 1996). Multi-span systems can be advantageous especially where required road can be reduced; it improves deflection, increases payload, shortens the overall rigging time due to fewer yarding corridors to access similar volume of wood, and reduces residual stand damage in partial cuts (Pavel, 1999). Clamping carriages with chokers are beneficial in partial cutting as they allow for better lateral yarding. Lateral yarding is critical in partial cut cable units to efficiently remove felled trees from the residual timber along the yarding corridor and makes partial cutting a cost effective operation (MacDonald, 1999). If timber is to be harvested as a strip surrounding the yarding corridor, a slackpulling clamping carriage is not required as lateral yarding is not necessary.

Cable partial cutting costs ranged from 1.31 to 1.46 times more expensive than cable clearcut units because residual trees in a partial cut increased time and cost for road changes (Bennett, 1997;Riggs et al., 1996). Differences in tree size, species composition and terrain characteristics between the Coastal Western Hemlock (CWH) and ICH biogeoclimatic zones render these results to be inaccurate for the interior of BC. A study in the interior of BC on a cedar dominant stand stated that partial cutting was operationally feasible but failed to provide any economic benefits (Walters, 1997b). Second growth partial cutting in the ICH had yarding cost of $14.56/m^3 while an old growth stand had a yarding cost of $12.11/m^3 (Pavel, 1999; Dunham and Gillies, 2000). No published results exist for clearcut yarding in the ICH.

3.4 Loading and Processing

Effective utilization of the loader is essential to ensure that the landing is clear and safe and that trucks are loaded with a minimum delay (Pavel, 1999). In the interior of BC, common loading equipment includes both front-end loaders (wheel based) and hydraulic loaders (track based). Front-end loaders are limited to relatively flat large landings. Wheel loaders also travel faster than hydraulic loaders on flat ground, this allows for sorting to be less restricted than with a hydraulic loader, provided landing space is not restricted. A butt 'n top loader effectively handles small-diameter trees while heel boom loaders are suited to confined areas but the ability to sort large timber is restricted by the number of logs that can be piled within an area immediately adjacent to the loader (MacDonald, 1999).

Processing methods are largely determined by harvesting method or by tree size characteristics. Mechanical processing has greater production than manual processing but requires greater capital investments (MacDonald, 1999). Where tree size restricts mechanical processing, manual processing is used. Manual processing is generally completed on the landing or roadside and therefore requires the bucker and machine operator be aware of each other's presence for safety reasons and to reduce the risk of accidents.

The loading cost for partial cutting is currently unavailable in the ICH, however, in the CWH, the loading cost per cubic meter in partial cuts ranges from 1.31 to 1.46 times greater than clearcut units due to greater non-productive delays in the partial cut units (Bennett, 1997). The loader waited for wood to process longer in the partial cut units than the clearcut due to the longer yarder cycle times (Bennet, 1997).

3.5 Stand Damage

When assessing stand damage, many sampling methods can be used. These sampling methods include random plot sampling, systematic transect, blocks along yarding or skidding corridors, systematic plot sampling, and sampling each tree in a unit (Han and Kellogg, 2000). The most efficient method of sampling is systematic plot sampling (Han and Kellogg, 2000). Trees may not be considered acceptable as a residual crop tree if they exceed any of the following thresholds (Pavel, 1999):

- A wound that girdles 1/3 of the stem circumference
- A wound on a supporting root
- A gouge in the stem
- A wound exceeding 400 cm^2 on the stem

Damage in skyline partial cutting in the ICH was 5.4% of the stand with 2.4% considered unacceptable for residual crop trees (Pavel, 1999). In coastal skyline partial cuts, damage rates were significantly higher, up to 10% of the residual stand, and may have been the result of the crews being inexperienced with partial cutting (Bennett, 1997; Boswell, 2001). When the yarder's running lines were too low, the incidence of tree scaring increased due to a lack of controlling turns (Bennett, 1997). A reduction in stand damage can be achieved through good carriage control when passing through intermediate supports and precise carriage positioning when beginning lateral yarding (Pavel, 1999).

The majority of stem damage is located on hauling roads and yarding corridors where the most harvesting activity occurs (Bennett, 1997; Pavel, 1999; Han and Kellogg, 2000). In ground-based partial cuts, the orientation of harvest units and directional felling play an important role in reducing stand damage. Skid trails should be aligned as straight as possible to reduce possible stand damage. To reduce stand damage on skid trails, the use of rub trees, protective culverts or higher stumps on the edge of skid trails are also recommended (Bennett, 1993; Matzka, 1998; Kosicki, 2000a). These rub trees are then carefully removed once harvesting is completed. Motivated operators can also result in less residual stand damage (Langeson, 1997). This can be implemented through a bonus/penalty system (McNeel and Dodd, 1996). In the case of partial cutting, it is expected that 5 to 10% of the residual stand may be lost to logging damage (Smith and Lamson, 1982).

4 Methods

4.1 Harvesting System Description and Specification

The choice of harvesting systems was based on stand and terrain characteristics including slope constraints, tree sizes and common local harvesting systems. The systems selected for the harvesting process were conventional, semi-mechanized, and cable (Table 1). Pictures of equipment utilized on each of the study sites are in Appendices 1 and 2.

Table 1 Components of harvest systems, designation and description

Harvest System	Felling Operation	Primary Transportation	Landing Operation
East Twin Creek			
Conventional	Manual felling	Rubber-tired skidder equipped with a winch line	Wheel log loader Manual processing
Cable	Manual felling	Tower yarder, using a running skyline system	Track log loader (Heel boom). Manual processing
Minnow Creek			
Semi-mechanized	Manual felling and feller buncher.	Rubber-tired skidder equipped with a grapple	Wheel log loader. Manual processing

Manual Felling was utilized in all three harvest systems. A high degree of butt flare in cedar in combination with butt rot made directional felling difficult and at times dangerous. Manually felled trees were generally felled in a downhill direction as the trees were leaning and weighted by branches to fall in that direction. Where tree conditions did not permit, the trees were felled in another safe direction. During manual felling, approximately 1 meter of snow was present, however shovelling around the base of the tree was not required for the majority of trees, as most stems were free of snow at cut height and the snow did not hinder the feller's movement. Mechanical felling was only used in the semi-mechanized harvest system. Primary transportation methods varied between the three harvesting systems, utilizing a yarder, line skidder, and grapple skidder. Manual processing (delimbing and bucking) at the landing was utilized as tree size and defect characteristics prohibited mechanized processing. Loading was done during and immediately after harvesting. Other primary duties of the loader included sorting timber on the landing, assisting the bucker by separating timber, clearing processed timber, and clearing slash and waste from landing to promote bucker safety.

4.1.1 Conventional System

The conventional system is a ground-based system that utilized manual felling. Timber was felled in a bunched manner, when possible, allowing for more trees to be choked at once. Wheel based skidders with a winch line extracted logs from the stand to the landings. A conventional system is typically used for terrain that has a sustained slope of ≤ 35%. Manual processing and loading, using a wheel based front end loader, occurred at the landing. Due to time of harvest, logs at certain landings were decked until the spring time when road weight restrictions (≤70% of the legal weight) were lifted.

4.1.2 Semi Mechanized System

The semi mechanized system was a ground-based system that is suitable for terrain that has a sustained slope of ≤ 35%. Mechanized (feller buncher) and manual felling methods were utilized depending on tree size and characteristics such as defect levels and species. Large cedar trees were mechanically felled through multiple cuts and pushed by a feller buncher, as a result of being hollow or rotten in the center. Large spruce were not felled using the same methods as the spruce was solid and the multiple cuts and pushing required would have resulted in unnecessary stump pull and butt shatter. A wheel-based skidder with a grapple was used to extract logs from the stand to the landings. The use of a feller buncher allowed felled trees to be bunched or grouped prior to skidding to improve the efficiency of the grapple skidder. As a grapple skidder was used to transport the timber, the trees were felled in a fashion that the butts faced the skidding direction, wedging the timber into the grapple when dragged. Trees tend to slide free from the grapple or required greater grapple pressures, resulting in increased breakage, when skidded from the top. Hoe chucking was utilized to orient and group the logs butt first for grapple skidding in steeper locations. Manual processing and loading, with a wheel based front end loader, at the landing was utilized. Logs were decked on the landing only until trucking was arranged.

4.1.3 Cable System

A cable system was utilized where slopes were > 35%. Manual felling was implemented due to large tree sizes and steep terrain. A tower yarder using a running skyline system was utilized and trees were felled downhill and manually processed. Yarding was accomplished by partially suspending the logs to avoid hanging up on the remaining stumps and slash. Partial suspension was accomplished by pulling the mainline in while dragging the haulback brake. Manually processed logs were decked with a track based heal-boom until spring road weight restrictions were lifted.

4.2 Study Sites

The study consisted of two harvest areas located between 32 and 35 km west of the town of McBride in the Rocky Mountain Trench in central British Columbia, and was part of the

Northern Rockies ICH / Silvicultural Systems Project (Jull et al., 2002). The study areas located at East Twin Creek and Minnow Creek, referred to as East Twin and Minnow from here on, are dominated by western red cedar with components of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmanii* Parry ex Engelm.), and western hemlock. Both sites are located in the Goat River Wet Cool ICHwk3, a wet cool variant of the interior cedar hemlock biogeoclimatic zone (DeLong et al, 1994; BC Ministry of Forests, 1996b; 1996c).

4.2.1 East Twin

The East Twin study area is located 35 km west of McBride, BC on the north-eastern side of the Fraser River (53° 30' N, 120° 20' W). The East Twin drainage is a relatively narrow, generally steep-sided valley running perpendicular to the Rocky Mountain Trench. This area is located between 1.5 km and 3.5 km on the East Twin Forest Service Road, branching from 7.3 km on the Mountainview Forest Service Road. The study area is 950 to 1050 meters above sea level (msal) and has a northwest aspect. Two harvesting systems, cable and ground-based, were used to harvest two separate treatment units (Appendix 3). The cable harvesting system was utilized on the steepest part (>35% slope) of the 100 % removal treatment while the remainder, 1.1 hectares, of the 100% removal treatments and entire group selection treatment (30% removal treatment) were harvested by a ground-based conventional system. In the group selection treatment, average harvest patches of 0.2 hectares in size were laid out (Table 2) with a skid trail system that would allow for multiple entries.

Table 2 Harvesting treatment descriptions for East Twin and Minnow sites

Study area	Treatment	Harvest system	Treatment area (ha.)	Size of internal harvest groups / leave patches
East Twin	Group selection (30% removal)	Ground-based	8.7	0.1-0.3 ha. harvest groups; Average = 0.2 ha.
	Clearcut (100% removal)	Ground-based	1.1	N/A
	Clearcut (100% removal)	Cable	6.7	N/A
Minnow	Group selection (30% removal)	Ground-based	11.2	0.1-0.3 ha. harvest groups; Average = 0.2 ha
	Group retention) (70% removal)	Ground-based	10.7	0.1-0.3 ha. leave patches; Average = 0.2 ha
	Clearcut (100% removal)	Ground-based	7.4	N/A

Table 3 East Twin site and stand description

Silvicultural treatment	Group selection ground-based	Clearcut - ground-based	Clearcut - cable
Elevation Range (m)	900 – 1050	900 – 1050	900 - 1050
Aspect	NW	NW	NW
Treatment size (ha)	8.7	1.1	6.7
Harvested area (ha)	2.1	1.1	6.7
Previously harvested area (ha)	0	0	0
Slope (avg.)	0-50% (20%)	0-30% (15%)	30-130% (55%)
Species (%)[a]			
Western red cedar	86.6	79.1	90.3
Subalpine fir	3.4	9.3	2.8
Engelmann spruce	10.0	5.6	2.2
Western hemlock	0.0	6.0	4.8
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]	349.0	441.6	433.0

[a] Provided by the BC MOF Cruise report.

[b] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF

4.2.2 Minnow

The Minnow study area is located 32 km west of McBride, BC on the north-eastern side of the Fraser River (53° 28' N, 120° 18' W), just south of the East Twin drainage system. This area is located 3 km on the Minnow Creek Forest Service Road, branching from 5.5 km of the Mountainview Forest Service Road. The study area is 1050 to 1200 masl and has a southwest aspect. The site was harvested using a semi-mechanized system with 30 %, 70 % and 100 % tree removal in group selection, group retention and clearcut treatments (Appendix 3). The primary goal of the layout in the group retention treatment was to ensure that all of the harvested area was about two tree lengths to a retention patch or and unharvested block boundary. The removal patches in the group selection treatment had an average size of 0.2 hectares and the group retention treatment had leave patches of ~ 0.2 hectares.

Table 4 Minnow site and stand description

Silvicultural treatment	Group selection	Group retention	Clearcut
Elevation Range (m)	1050 - 1200	1050 – 1200	1050 - 1200
Aspect	SW	SW	SW
Treatment size (ha)	11.2	10.7	7.4
Previously harvested area (ha)	0.2	1.5	0.0
Harvested area (ha)	3.6	6.1	7.4
Slope (avg.)	0-50% (30%)	0-30% (15%)	0-40 (30%)
Species (%)[a]			
Western red cedar	60.4	46.5	75.0
Subalpine fir	19.4	27.3	11.4
Engelmann spruce	18.3	24.6	13.0
Western hemlock	1.9	1.6	0.3
Stems/ha [a]	349	288	394
Average DBH (cm)[a]	44.7	47.1	48.2
Average height (m)[a]	25.4	26.0	25.9
Gross vol. (m^3/ha)[a]	819.8	659.4	1122.1
Net merchantable vol (m^3/ha) [b]	367.6	308.8	359.2

[a] Provided by the BC MOF Cruise report.
[b] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF

4.3 Study Techniques

A field-based, observational study was conducted to evaluate the effect of various silvicultural prescriptions on harvesting productivity and cost in the ICH stands. Replication and modification of treatments and harvesting systems was not possible due to time and cost constraints. Comparison of costs among alternative logging systems requires accurate production data. The collection of this data was difficult due to the variations in the logging environment (Olsen and Kellogg, 1983). To successfully calculate the productive and non-productive time, detailed time studies were conducted. This data was then used to determine the cycle element durations, and calculate interactions between equipment, personnel, and harvesting attributes. The methods used for timing included shift level studies, detailed time studies, and activity sampling on landing areas.

4.3.1 Shift Level Studies

Shift level studies are daily production averages based on a worker's record of pieces handled per unit work time (Olsen and Kellogg, 1983; Olsen et al., 1998). In this study, cooperation was requested from each equipment operator and other key personnel to collect accurate production information at the end of every shift. The following information was collected from equipment operators and ground personnel on a daily basis (only information pertinent to an individual position was requested):

- Date
- Unit# (for removal patches)
- Treatment area(s)
- Operator(s) name(s)
- Weather conditions
- Equipment description or number
- Shift length and break times
- Non-productive time (> 10 minutes and reason for delay)
- Pieces handled (trees, logs, tops, etc.)
- # of cycles (i.e. turns skidded or yarded, or trees felled)
- General comments outlining the day's production

To ensure reliability in cycle and piece numbers, equipment operator and ground personnel used mechanical counting devices (tally counters) for keeping track of log and cycle counts. In addition, when changing treatments, an additional shift level form was filled out. The shift level forms were collected at least biweekly and daily when possible to ensure that the forms were being completed properly (Appendix 4). In addition, since all of the operators were paid on an hourly basis and not on productivity, there was little incentive for them to bias the data

4.3.2 Detailed Time Studies

A handheld computer (Ranger 9600) was used for detailed time studies. Time and conditions required for each turn were recorded. A turn is described as the sequence of work elements required to bring a group of logs or trees to the landing. Detailed timing includes the cycle element timing for each phase of harvesting (felling, skidding, and yarding) and recording of delay descriptions. Both independent variables (slope, turn size, etc) and detailed time data (dependent variables), were collected (Appendix 5). Detailed timing data was conducted by two researchers at each site. A standard training program ensured both researchers collected data using the same techniques and methods. In addition, each researcher timed only one harvesting component, skidding / yarding or felling, but not both. Manual felling, line skidding, and yarding was timed in East Twin, while only mechanized felling and grapple skidding was timed in Minnow due to limitations in funding and manpower. In the East Twin clearcut unit, tree diameter at cut height data was collected. This data was not collected in the other East Twin and Minnow treatments due to safety concerns and manpower constraints.

4.3.3 Activity Sampling

Activity sampling measures the proportion of the workday spent on a series of activities by individual machines and people (Matzka, 1998). Activity sampling also measured the interactions of equipment and personnel at the landing. Observations may be made at random times or at equally spaced intervals. If at equally spaced intervals they are called fixed-interval, systematic, group timing, or multi-moment sampling (Olsen and Kellogg, 1983; Olsen et al., 1998). An equally spaced time intervals method was chosen and set at 20 seconds for a minimum of an hour to ensure the accuracy of the data as recommended by Olsen and Kellogg (1983). Each landing was sampled in the morning with a measurement starting time of 9:00AM to 11:00AM.

4.4 Specific Methods

4.4.1 Objective 1 - Determine planning/layout cost for partial cut and clearcut blocks

The planning and layout costs were calculated by dividing the total cost of planning and layout by the total volume removed for each treatment. The cost per unit volume were determined for each treatment and site using volume data obtained from the BC Ministry of Forests (BC MOF) along with person hours and corresponding hourly costs provided by consultant and UNBC researchers. The volume information was provided by species and treatment from the BC MOF from piece scale data. The final volume, not the raw data, by treatment and species was only information provided as such no further analysis was conducted on the data. The timber was scaled in accordance with the BC MOF regulations (BC Ministry Forests, 1995) by multiple scalers. The consultant was responsible for location and marking of boundaries, office analysis of field data (cruise), and creation of maps. Cruise data provided was also conducted in accordance with the BC MOF regulations (BC Ministry Forests, 1996a). University researchers determined the location of skid trails and residual and removal tree selection and marking. Data collected for calculating the planning and layout costs included:

- Date
- Treatment area
- Volume of timber harvested in each treatment.
- Person hours spent by the crew in:
    - Location and marking of skid trails/boundary
    - Office analysis of field data (cruise) and creation of maps
    - Residual and removal tree selection and marking

Treatment planning and layout costs ($\$/m^3$) were calculated by dividing the total planning and layout costs for each treatment by the provided BC MOF merchantable volume for that treatment [1]. Hectare costs were calculated for both harvest and treatment area using the same formula [2].

[1] Planning and layout costs ($\$/m^3$ - by treatment):

$$\text{Planning and layout costs } (\$/m^3) = \frac{\text{Total planning and layout costs}}{\text{BC MOF scaled volume } (m^3)}$$

[2] Planning and layout costs ($/ha - by harvest or treatment area):

$$\text{Planning and layout costs } (\$/ha) = \frac{\text{Total planning and layout costs}}{\text{Harvest or treatment area (ha)}}$$

4.4.2 Objective 2 - Compare production rates (m^3/hr) and cost ($\$/m^3$) for various silvicultural prescriptions using ground-based and cable harvesting systems

The production rates and cost per unit volume for each treatment was determined through the use of shift level and detailed time studies in combination with the provided BC MOF scaled treatment volumes.

4.4.2.1 Production Rates and Cost per Unit Volume Calculations

The shift level and detailed time study was used to calculate the productive and non-productive times in a cycle. The non-productive cycle time was calculated from both the shift level (for larger delays > 10 minutes) and detailed time study (for small delays < 10 minutes). These delays were subtracted from the scheduled machine hours (SMH) for each piece of equipment and used to calculate the effective or productive machine hours (PMH). The average productive cycle time was calculated from the detailed time study information (Appendices 8 to 10, 12, and 13).

[3] Effective hour:

Effective hour (min/hr) = 60min × (1 - % delay time per scheduled machine hour, SMH)

[4] Cycles per hour:

$$\frac{\text{Cycles}}{\text{Hour (SMH)}} = \frac{\text{Effective hour (min/hr)}}{\text{Average productive cycle time (min/turn)}}$$

Once cycle times were calculated, the volume associated with each cycle was determined [5] along with the hourly production [6].

[5] Volume per cycle:

$$\frac{\text{Cubic meters}}{\text{Cycle}} = \frac{\text{Merchantable volume (m}^3\text{)}}{\text{Piece}} \times \frac{\text{Pieces}}{\text{Cycle}}$$

[6] Hourly production (m^3/SMH):

$$\frac{\text{Cubic meters}}{\text{Hour (SMH)}} = \frac{\text{Cycle}}{\text{Hour (SMH)}} \times \frac{\text{Cubic meters}}{\text{Cycle}}$$

Individual machine cost was calculated using individual ownership and operating costs (Lambert and Howard, 1990). The cost of ownership for each piece of equipment is based on factors such as book price, interest rates, book salvage value, depreciation period, taxes, and insurance. The operating costs include fuel and oil consumption, labour, and operating supplies (Mifflin, 1980). Appendices 6 and 7 contain the machine rates for each machine used in the study.

Production cost ($/m^3) for each machine was calculated by dividing the production rate by the appropriate machine ownership and operating costs (Lambert and Howard, 1990) [7]. As all the machines involved in harvesting had different production rates, all of the productive costs were determined independently from one another. The overall production cost of the harvesting system was calculated by the summation of the productive costs for each machine utilized (Lambert and Howard, 1990).

[7] Final harvesting cost (by equipment):

$$\frac{\$}{\text{Cubic meters}} = \frac{\text{Ownership \& operating cost (\$/SMH)}}{\text{Hourly production (m}^3\text{/SMH)}}$$

In the Minnow units, both manual felling and mechanized felling occurred. While the observed costs could be determined using the previous formulas [3-7], the contribution of each process had to be calculated and weightings applied. The weighting was calculated as follows:

[8] Weighted average of costs = Observed cost * N_1 / N_2

Where:
Observed costs = cost of observed process ($/m^3)
N_1 = Trees affected by observed process
N_2 = Total trees in the treatment

This formula was used to calculate the weighted cost of manual felling, mechanized felling, and hoe chucking. For total felling cost, the weighted manual and weighted mechanized felling costs are combined.

In addition to direct harvesting production costs, landing and skid trails as well as moving costs were calculated. Skid trail and landing construction costs were calculated from the number of hours to construct the trail and landings and corresponding costs for each treatment. The volume of timber removed from that treatment was then divided into the corresponding costs using the same formula as planning and layout [1]. Moving costs of equipment was also calculated for each treatment using equation 1. Average moving cost was $600 per piece of equipment based upon a 35km round trip in the McBride area. This was based on quotes from local contractors. Moving costs where the equipment was shared for multiple treatments were weighted according to volume removed from each treatment were calculated using equation 8.

4.4.2.2 Standardization and Sensitivity Analysis

Tree volume has a large effect on the overall harvesting costs (Mann and Mifflin, 1979; Kluender et al., 1997). Skidding productivity is typically the most expensive component in a whole tree harvesting operation and directly dependent on skidding distance (Mitchell, 2000). To understand better the influence of tree size and skidding distance on harvesting cost, standardized values of tree size and skidding distance were used to compare costs for planning and layout, skidding, processing, and loading between silvicultural treatments.

The standardization of merchantable volume per piece was calculated by substituting set values for the merchantable volume per tree [Equation 5] and recalculating the hourly production [Equation 6] and the final harvest cost [Equiation 7] for each harvesting process.

Skidding distance was standardized using the following methodology. A standard skidding distance of 100 meters was entered into the derived general linear models (described in the following section 4.4.3), while holding all other variables at their recorded average values, to calculate the total productive cycle time.

Standardized values for merchantable volume per tree and skidding distance were used in the derived general regression models (described in the following section 4.4.3), while holding all other variables at their recorded average values. This allowed the calculation of the total productive cycle time under the same condition of merchantable volume of tree size and skidding distance. This productive cycle time was then used to calculate the cost per cubic meter using the formulas [Equations 3-7] listed in section 4.2.2.1. After initial standardized cost comparisons were completed, sensitivity analysis was conducted to see how these two variables affect harvesting costs, while holding all other variables constant (Figures 6-10 and 12-13).

4.4.3 Objective 3 - Derive harvesting production prediction models based on appropriate independent variables

For each harvesting component where detailed time studies were conducted, harvesting prediction models were developed using the dependent and independent variables collected. Both continuous and categorical independent variables were collected. All data analysis and model creation was conducted using Systat 11 and Microsoft Excel 2003. The data collected in the detailed time studies was entered into Systat 11 and checked form normality through the creation of probability plots (Q-Q). The data was then taken into a Microsoft Excel spreadsheet, where an initial screening of data was performed. Outliers were screened and removed from the data set if they were more than 2 standard deviations from the mean. The data was rechecked for normality post screening using Systat 11using a probability plot (Q-Q). A general linear model was then created using a stepwise process (α=0.05). When independent variables were shown to be insignificant ($P>0.05$), they were removed and the general linear model was rerun. A residual plots and lack of fit statistic were created for each model revision. A straight line relationship of predicted values versus residual values in the residual plot ensured that the data shows evidence that the distribution is normal in nature. The significance of the independent variables was noted and a production model equation created.

4.4.4 Objective 4 - Quantify residual stand damage for the different partial cutting prescription blocks

Post harvest examination of retention patches and designated skid trails was conducted in group retention and group selection treatment units. The block boundaries were also examined in the clearcut and group retention treatments. Damage was quantified in three main categories; root, stem, and crown damage. Root and stem scarring damage was measured using a tape measure. The width, depth, and length of each scar or gouge were recorded as well as its orientation and location on the tree and in the stand. Crown damage was measured using a clinometer when the proportion of impacted live crown > 50% (Han and Kellogg, 2000). Sampling was completed using a systematic line transect sampling method. The intensity of the sample was determined by the following formula calculation of the number of damaged trees needed for sampling (Thompson, 1992):

[9]

$$n_0 = \frac{N * p (1 - p)}{(N - 1)(d^2 / z^2) + p (l - p)}$$

where:

n_0 = number of damaged trees required in sample.

N = total number of trees in the unit.

p = estimate of % damaged trees in unit. The formula depends on the unknown population proportion p. If no estimate of p is available before the survey a “worst case” value of p = 0.5 can be used to determine sample size.

d = width of the confidence interval, 5% in this study (d= 0.05).

z = the upper α/2 point of the normal distribution (1.96 for 95% probability; α=0.05)

Once the number of damaged trees to be sampled was calculated, the sample area required was derived. It was decided to apply the same sampling system at all sites to avoid sampling error. Systematic transect sampling was initially chosen because there would be no damage beyond one tree length from the boundary of openings and skid trails. It also provides relatively consistent results and the low standard deviation (Han and Kellogg, 2000). The systematic transects width was large enough to sample the residual-tree spacing but smaller than the transect line spacing to avoid overlapping. Areas of harvested openings were not considered part of the sampling area if traversed by a transect.

While sampling stand damage at the East Twin site, it was noted that all stand damage occurred within 5 meters of a skid trail or opening. As a result, the sampling method was changed to a systematic 25-meter wide strip along the edge of these features into the remaining standing timber for the Minnow Creek site; East Twin site was resampled using the 25-meter wide strip. Amount of damage present in the sample population was calculated by dividing the number of sampled damaged trees by the sample population. Damage to the residual stand was derived by dividing the number of sampled damaged trees by the number of residual stems in the stand. Residual stems were calculated by subtracting the number of harvested trees in each treatment from density information provided in the cruise data. An assumption was made that no harvesting damage occurred outside of the sample area and the density information in the cruise data provided was correct.

5 Results and Discussions

The East Twin and Minnow sites will be reported and discussed as separate individual case studies due to interaction of harvesting components and other variables such operator experience and work habit differences. These inherent site differences do not allow for direct comparison of the sites without first understanding each sites context.

5.1 East Twin

5.1.1 Planning and Layout

The planning and layout costs were highest, \$2.62/m^3, in the group selection because of the need to designate removal patches in the block and a more complex skid trail system (Table 5). The most expensive cost components in planning/layout was traverse and boundary marking, representing > 50% of total planning and layout cost. In all ground-based-treatments, recommended skid trails were marked. 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. Pre-existing landings from earlier 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. 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 field survey requirements to ensure adequate deflection for cable yarding throughout the block.

Table 5 Summary of East Twin planning and layout costs

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Traverse and boundary cost ($)	1095.00	232.75	1248.41
Deflection cost ($)	n/a	n/a	730.00
Mapping cost ($)	78.75	12.55	67.34
UNBC group selection layout cost ($)	750.00	n/a	n/a
Total cost ($)	1923.75	245.31	2045.74
Final volume (m^3)[a]	733.00	458.80	2987.90
Layout / planning cost ($/$m^3$)	2.62	0.53	0.68

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF

5.1.2 Harvesting Operations

5.1.2.1 Felling

Manual felling was the only method used partially or fully for all harvest units because of large tree size (mean dbh was 53.2 cm) and steep slopes. When utilizing downhill felling and top choking/hooking, breakage was a concern due to high decay levels, however breakage occurred in < 2% of the felled and skidded timber. Contractor A and B had separate fellers with similar amounts of felling experience (20 years). Felling production from the cable clearcut is the highest at a cycle time of 1.97 minutes per tree (Table 6). This results in a corresponding volume production of 358.08m^3 felled timber per 8-hour shift at a cost of $1.12/$m^3$ (Table 7). The second highest felling production occurred in the group selection. The group selection cycle time was lower than that of the ground-based clearcut even though precise directional felling was required. 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 difference between the group selection and ground-based clearcut was only

$0.20/m^3. A study in south east BC that had a tree size of 0.93m^3/tree had similar manual felling costs ranging from $2.11/m^3 to $2.28/m^3 (Kockx and Krag, 1993). A more complete summary of the felling cycle elements is located in Appendix 8.

Table 6 Summary of East Twin felling cycle times

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Feller	A	A	B
Average time (min/cycle)			
Total productive time	1.86	1.98	1.29
Total non-productive time	1.27	1.60	0.68
Total cycle time / tree	3.13	3.58	1.97
Average time (%/cycle)			
Total productive time	59.6	55.4	65.5
Total non-productive time	40.4	44.6	34.5
Total cycle time	100.0	100.0	100.0

Table 7 East Twin felling productivity and cost

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Feller	A	A	B
Net volume per tree (m^3)[a]	1.22	1.54	1.47
Volume per hour (m^3/hr)[b]	23.37	25.81	44.76
Labour and equipment cost ($/hr)[b]	50.00	50.00	50.00
Felling cost ($/m^3)[b]	2.14	1.94	1.12

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF

[b] All costs and productivities are reported for scheduled machine hours.

The results from this study indicate that total cycle time, tree size, and decay percentage can have an effect on the production. Designation of skid trails, tree species, feller, and treatment type were significant factors relative to the delay-free cycle time (Table 8). Slope was found to be not significant (P>0.05). Equation 10 describes the delay-free cycle time for manual felling for all three East Twin treatments, determined from a general linear model analysis.

According to the general linear model, treatment type was a redundant variable as its contribution was accounted for by the feller, road, and species variables; as such it was not included in the model.

Table 8 Significance of East Twin independent felling variables to total productive cycle time

Independent variables	P value
Slope	0.479
Skid trail designation	0.004
Feller	0.001
Tree species	0.000
Treatment	0.001

[10] Total productive cycle time (min) = $1.087 - 0.179F + 0.658S_1 - 0.332S_2 + 0.0727S_3 + 0.292R$

Where :
F = Feller (a=1, b=0)
S_1 = Tree Species – western red cedar (if yes = 1, no = 0)
S_2 = Tree Species – western hemlock (if yes = 1, no = 0)
S_3 = Tree Species – subalpine fir (if yes = 1, no = 0)
R = Non-designated skid trails (if yes = 1, no = 0)

Sample number = 656 R^2 = 17.9% Standard error of estimate = 1.01

In the cable unit, tree diameter data was collected. Slope and tree species data was also collected as independent variables, however it was found that only diameter was significant ($P<0.05$) (Table 9). Equation 11 describes the delay-free cycle time for manual felling for a cable-harvested unit, determined from a general linear model analysis. A significant linear relationship was found between cycle time and diameter. Figure 1 illustrates the relationship of productive felling cycle time to diameter.

Table 9 Significance of East Twin cable unit independent felling variables to total productive cycle time

Independent variables	P value
Slope	0.670
Diameter	0.000
Tree species	0.452

[11] Total productive cycle time for felling (min/cycle) = 0.040 + 0.020 * Diameter (cm)

Sample number = 194 R^2 = 61.3% Standard error of estimate = 0.469

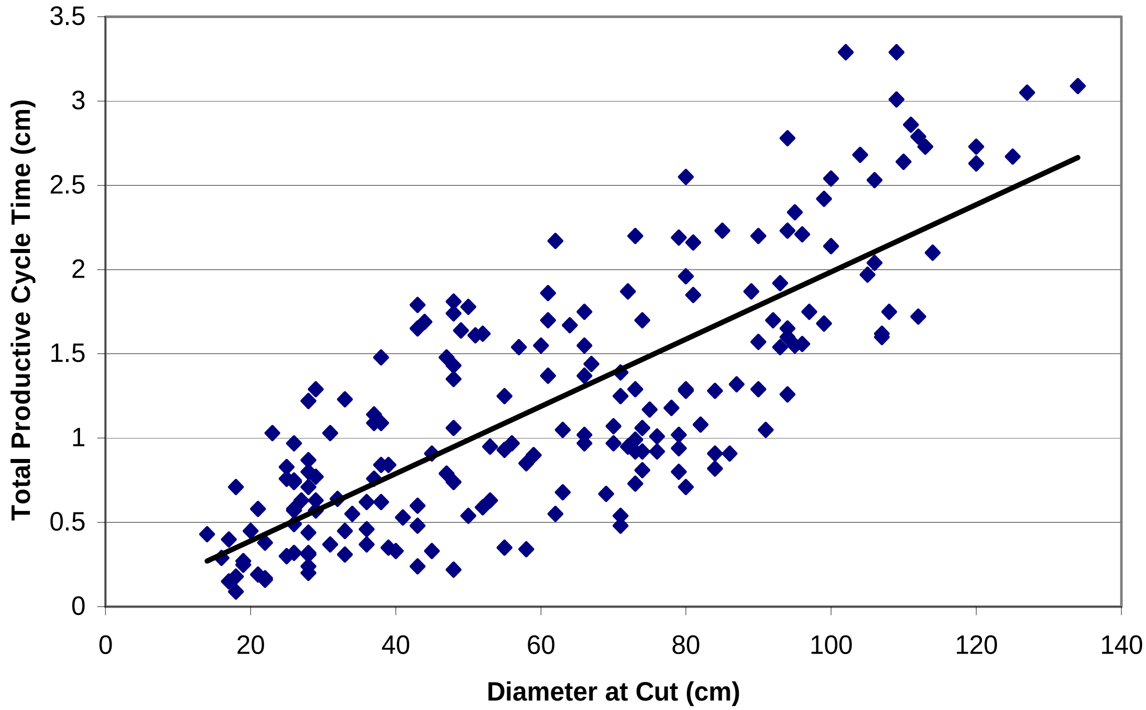

Figure 1 Relationship between total productive cycle time for felling and tree diameter for the East Twin cable treatment

5.1.2.2 Primary Transportation

5.1.2.2.1 Skidding

Detailed skidding productivity for the John Deere 640 D line skidder is displayed in Table 10 and 11 for both treatments. A more complete summary of the skidding cycle elements is reported in Appendix 9. The costs were \$4.13/m^3 to \$4.47/m^3 for the clearcut and group selection treatments respectively. A study in a spruce dominant stand where the treatment types were identical, 30% retention and clearcut, and the spread of average skidding distances was 69 meters; the treatments had a skidding cost difference of $0.59/m^3 (Sambo, 2003). The cost difference in this study was only $0.34/m^3 while the skidding difference was 99 meters; however the clearcut unit had a greater proportion of non-productive time, causing an increase in the cycle time.

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. The operator felt the bladed trails would allow for more wood to be hauled because of less obstruction from stumps and other remaining debris, and the longer travel time required more volume to be delivered to the landing in order to be financially viable. The average skidding distance in the group selection was 284 m, which was 143 m longer than in the clearcut. As well, an additional 1.5 logs were delivered to the landing per turn in the group selection each cycle resulting in longer cycle times. This resulted in a cycle time that was 2.83 minutes greater in the group selection treatment.

Table 10 Summary of East Twin ground-based skidding cycle time

Harvesting system	Ground-based	
Silvicultural treatment	Group selection	Clearcut
Average time (min/cycle)		
Total productive time	18.47	15.50
Total non-productive time	2.87	3.01
Total skidding cycle time	21.34	18.51
Average time (%/cycle)		
Total productive time	86.55	83.74
Total non-productive time	13.45	16.26
Total cycle time	100.00	100.00

Table 11 East Twin skidding productivity and cost

Harvesting system	Ground-based	
Silvicultural treatment	Group selection	Clearcut
Average distance (m)	238.70	140.80
Average pieces/cycle (no.)	5.86	4.35
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)[b]	20.09	21.72
Skidder cost ($/hr)[b]	89.74	89.74
Skidding cost ($/$m^3$)[b]	4.47	4.13

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF

[b] All costs and productivities are reported for scheduled machine hours.

Figure 2 illustrates the proportion of each delay that constitutes the non-productive time. In the clearcut and group selection, 0.6% and 1.1% of the total cycle time respectively 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 that the line skidders were using. 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.

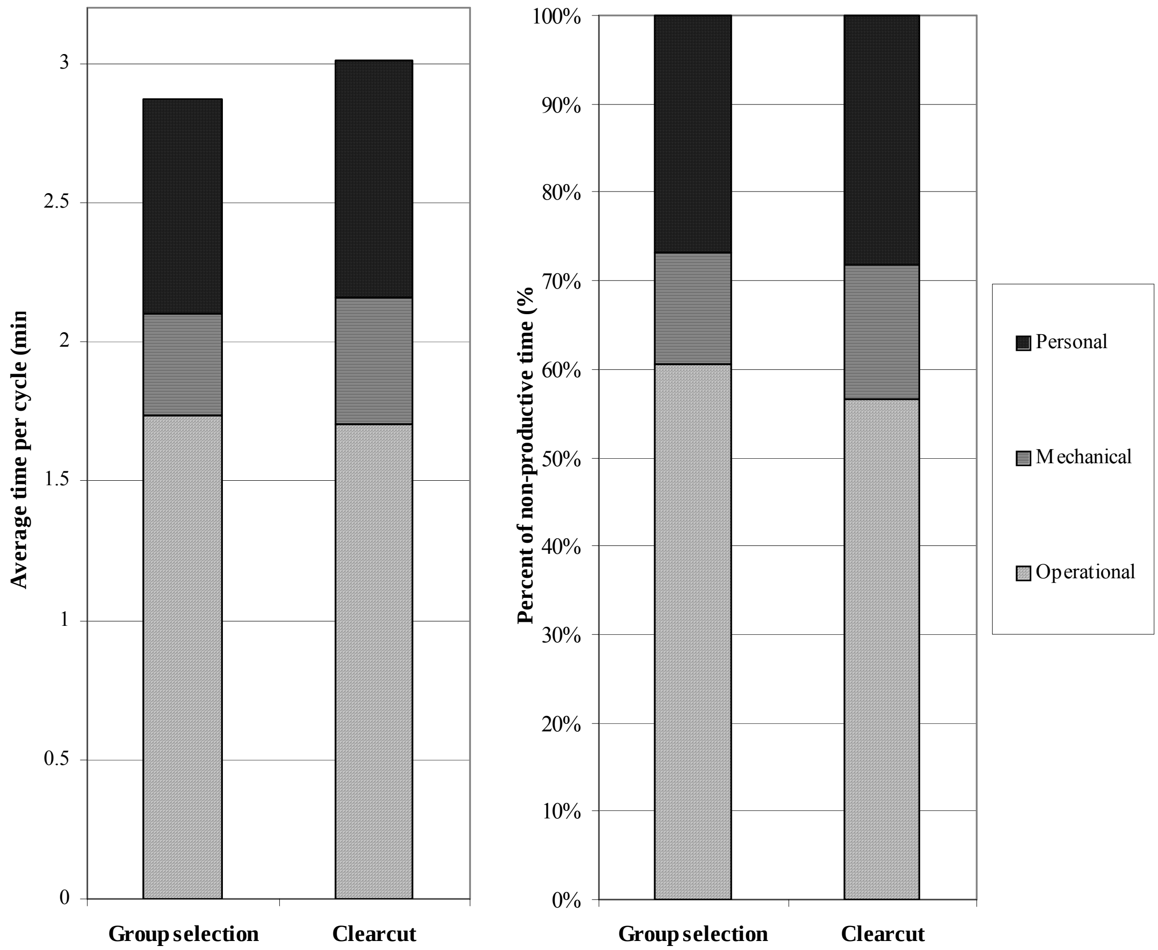

Figure 2 Summary of East Twin non-productive timing elements for skidding

Through a general linear model analysis, the following factors significantly influenced the delay-free total productive time: number of log skidded per turn, and skidding distance (Table 12). Average slope, treatment, skid trail designation, and number of chokers available were not significant factors (P>0.05).

Table 12 Significance of East Twin independent skidding variables to total productive cycle time

Independent variables	P value
Slope	0.789
Skid trail designation	0.299
Treatment	0.085
Logs skidded	0.001
Chokers present	0.278
Skidding distance	0.000

Equation 12 describes the total productive cycle time (delay-free) for a rubber-tired line skidder, determined from a general linear model analysis.

[12] Total productive time (min) = 8.321 + 0.023 * Distance + 0.745 * No of logs

Sample number = 139 $R^2 = 0.512$ Standard error of estimate = 3.243

5.1.2.2.2 Yarding

A Madill J7C tower yarder used a 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 156 meters. Cycle time data for this yarder is displayed in Table 13 and Appendix 10. The unit cost for yarding was $7.74/ m^3, which is 73.2% more expensive than skidding in the group selection and 87.2% higher than skidding in the ground-based clearcut (Table 11 and 14). While the production was similar to other skyline studies, 32.49m^3/PMH versus 25.7m^3/PMH to 37.9m^3/PMH (Hedin and Delong, 1993), the yarding costs were considered low in comparison to the costs reported from other studies in cedar dominant stands in the province. This might 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/hr higher plus benefits. The productive yarding time constitutes 75.1% 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, this is between two FERIC skyline analyses that were 10% (Dunham and Gillies, 2000) and 15% of the total cycle time (Kosicki, 2000b).

Table 13 Summary of East Twin yarding cycle time

	Average time (min/cycle)	Average time (%/cycle)
Total productive time	7.08	75.10
Total non-productive time	2.34	24.90
Total cycle time	9.42	100.00

Table 14 East Twin yarding productivity and cost

Harvesting system Silvicultural treatment	Cable Clearcut
Pieces per cycle (no.)	2.59
Net volume per tree (m^3)[a]	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)[b]	24.25
Yarder cost ($/hr)[b]	187.58
Yarding cost ($/$m^3$)[b]	7.74

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[b] All costs and productivities are reported for scheduled machine hours.

The hook up time was the most time consuming component, 46% of the total cycle time, followed by the inhaul element (Figure 3, Appendix 5). 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-slack pulling 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 only 2 chokers were utilized due to large tree size and the scattered distribution of felled trees. The felled logs were top choked as it was faster than butt choking due to decreased tree diameters.

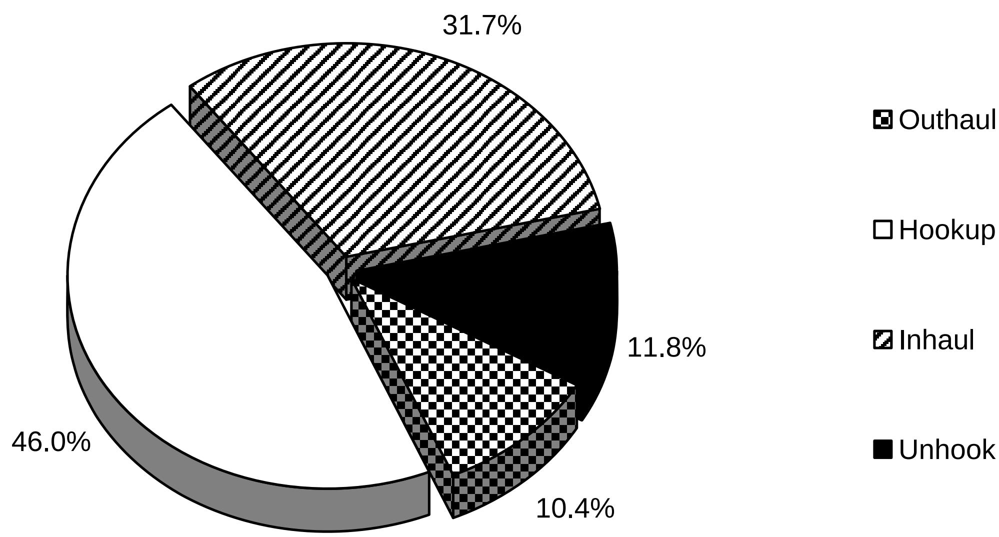

Figure 3 Productive cycle time distribution for East Twin cable yarding

Approximately 8.1% of the non-productive time, or 2.1% 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. A skyline study by Dunham and Gillies (2000) found the repair time to be lower at 2.0% of the total cycle time. The time to replace chokers accounted for 7.8% of the non-productive time.

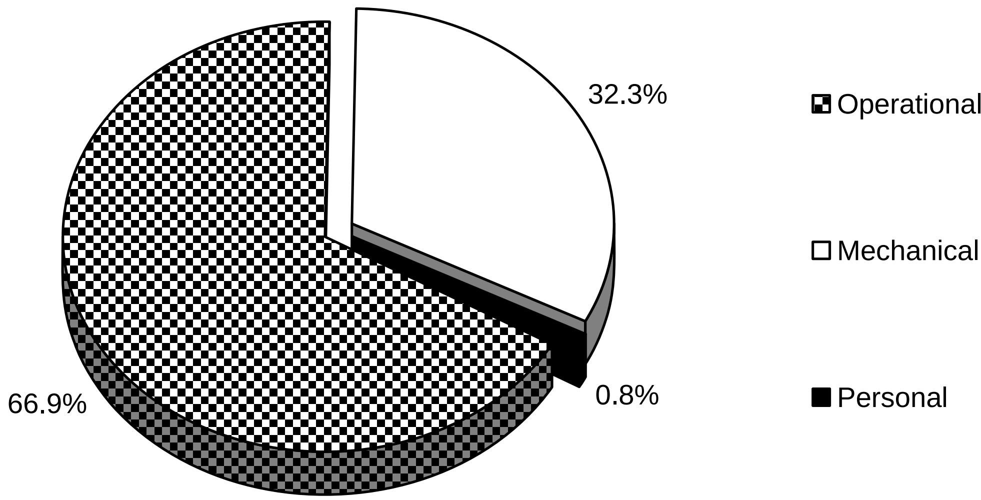

Figure 4 Non-productive cycle time distribution for East Twin cable yarding

Through a linear regression analysis, the delay-free total productive time, the number of logs yarded and yarding distance were found to be significant factors (Table 15). As the number of chokers available did not change throughout the study it was not considered. Average slope was found to be an insignificant factor.

Table 15 Significance of East Twin independent yarding variables to total productive cycle time

Independent variables	P value
Slope	0.487
Logs yarded	0.000
Yarding distance	0.000

Equation 13 describes the total productive cycle time (delay-free) for a single span, running skyline system, determined from a general linear model analysis.

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

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

5.1.2.3 Manual processing

Processing for all sites was completed manually at the landing. The primary consideration of processing was to maximize commercially valuable wood recovery such as saw logs and 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 16 and 17). The combined felling and processing costs were $\$2.27/m^3$ to $\$3.68/m^3$. A study in the ICH mc2 had combined costs of $\$3.23/m^3$ (Kosicki, 2000a).

Table 16 East Twin shift level summary for manual processing

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Bucker	A	A	B
Time (hrs)	45.25	18.75	138.00
Trees processed (no.)	601	298	2033
Gross volume per tree (m^3)[a]	2.66	2.14	2.14
Net volume per tree (m^3)[b]	1.22	1.54	1.47
Cost ($\$/m^3$)[c]	1.54	1.02	1.15

[a] Provided by the BC MOF Cruise report.
[b] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[c] All costs and productivities are reported for scheduled machine hours.

Table 17 East Twin species volumes for each treatment[1]

	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Volume (m^3)[a]			
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 (100.0)	485.8 (100.0)	2987.9 (100.0)

[1] Values in ( ) indicate % of the total volume.
[a] Net merchantable volume was provided by the BC MOF

The saw logs were required to have a 10cm shell (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 19m. These saw logs will be processed into small dimension aesthetic lumber. The post and rail timber required a 7.5cm shell. Post and rail timber required a minimum length of 2.5m and a maximum length of 19m. Bucker "A" was used in both ground-based treatments, while a different bucker was used in the cable clearcut, bucker "B". Bucker "B" was the owner of the cable operation. He felt that by processing the wood himself, he could achieve the maximum commercial value from the timber.

The combined decay, waste, and breakage estimates from the BC MOF cruise data for the ground-based group selection, ground-based clearcut, and cable clearcut treatments were 68%, 51%, and 52%, respectively. Observations support these numbers as a large incidence of butt and pocket rot in cedar logs was present. Butt and pocket rot not only destroy heartwood and sapwood, but also increases the possibility of breakage when felling and skidding/yarding. Increased breakage however was not observed during felling or skidding. 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 hemlock, spruce, and subalpine fir had little decay, thus was faster to process for the bucker. These species were processed for saw logs only.

In the cable block, it was observed that the bucker "B" was able to retrieve more commercial volume than bucker "A" from cedar, by processing the wood for both saw logs and post and rail timber. In the group selection and ground-based clearcut, the cedar was only processed for saw logs due to inexperience of Contractor "A" in processing defective cedar. 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 17).

5.1.2.4 Decking

Loading was not completed 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 equivalent to the decking cost. Loading costs were the highest in the group selection at \$5.32/m^3 because less skidded volume was available for the loader as a result of longer skidding cycle times (Table 18). The ground-based and cable clearcut cost is \$3.33/m^3 and \$5.01/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 front-end loader in the group selection. The contractor chose a heel-boom loader, as it requires less operating space on the landing than a front-end loader. In this yarding operation, landing area was minimal being only 45 by 45 meters. These costs are between values reported in previous studies such as \$6.81/m^3 (Pavel, 1999), \$2.32/m^3 (Pavel 2004), and \$3.52/m^3 to \$9.94/m^3 (Pavel, 2005).

Table 18 East Twin 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
Net volume per tree (m^3)[a]	1.22	1.54	1.47
Volume processed (m^3/hr)[b]	16.20	25.91	21.65
Equipment rate ($/hr)[b]	86.16	86.16	108.51
Cost ($/$m^3$)[b]	5.32	3.33	5.01

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[b] All costs and productivities are reported for scheduled machine hours

5.1.2.5 Other Harvesting Costs

Equipment moving cost and skid trail and landing construction costs should be considered as part of the final cost. The summary of moving costs was based on moving equipment from McBride to the harvest site, a 35km distance (Table 19).

Table 19 Summary of East Twin equipment moving costs

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Move in and out cost ($)	721.69	478.31	1200.00
Final net volume (m^3)[a]	733.00	485.80	2987.90
Cost ($/$m^3$)	0.98	0.98	0.40

[a] Net merchantable volume was provided by the BC MOF

The group selection required 15 hours of landing and skid trail construction to harvest a lower proportion of wood than the ground-based and cable clearcut, where only 7.5 hours was spent for landing and skid trail construction (Table 20). This resulted in a higher cost per cubic meter in the group selection. The cable and ground-based clearcut utilized the same landing and no skid trails were constructed, thus the construction costs were shared by a volume basis. As landings were pre-existing, and only required slight modifications to bring them up to legislative requirements, these results will not be included in the comparison of harvesting costs between treatments.

Table 20 Summary of East Twin skid trail and landing construction costs

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Time (hrs)	15.00	1.05	6.45
Equipment and manpower ($/hr)[a]	145.09	145.09	145.09
Final net volume (m^3)[b]	733.00	485.80	2987.90
Cost ($/m^3)[a]	2.97	0.31	0.31

[a] All costs and productivities are reported for scheduled machine hours.
[b] Net merchantable volume was provided by the BC MOF

5.1.3 Summary of Harvesting Costs

The unit cost ($/m^3) was lowest in the ground-based clearcut treatment (Table 21). The ground-based clearcut had the lowest costs because of minimal planning and layout requirements, and a higher volume of merchantable timber extracted per tree. The planning and layout 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 skyline corridor layout. The increased volume was the result of more non-cedar species with fewer defects than cedar. The low 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 due to shorter total felling cycle time and greater total volume being removed from the treatment, respectively. The group selection had the highest cost as a result of having the lowest merchantable volume per tree and long skidding distance. 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 increased by 2.83 minutes. This resulted in the bucker and loader waiting for wood to process.

Table 21 Summary of East Twin total costs (\$/m^3)[1]

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Layout/planning cost	2.62	0.53	0.68
Felling cost	2.14	1.94	1.12
Skidding/yarding cost	4.47	4.13	7.74
Processing cost	1.54	1.02	1.15
Loading cost	5.32	3.33	5.01
Total cost	16.09	10.95	15.70

[1] All costs and productivities are reported for scheduled machine hours.

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 compared to the ground-based clearcut. As a result of this higher volume, the ground-based clearcut has lower planning and layout, manual processing, skidding, and loading costs than the group selection or cable clearcut.

If the merchantable volume per tree was identical (1m^3/tree) in each treatment and the number of harvested trees in each treatment remained constant, the group selection harvesting system would cost \$19.63/m^3 due to a decrease in merchantable volume per piece (Table 21). This is an increase of \$3.54/m^3. The clearcut cable costs would also increase by

$7.38/m^3 to $23.08/m^3 because of decrease in piece size. The cost of the clearcut unit would increase by $5.91/m^3 due to a decrease in average piece size of 0.54m^3.

Table 22 Summary of East Twin total costs ($/m^3) at a standardized merchantable volume per stem of 1m^3 [1]

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Layout/planning cost	3.20	0.82	1.01
Felling cost	2.61	2.98	1.64
Skidding/yarding cost	5.45	6.36	11.37
Processing cost	1.88	1.57	1.70
Loading cost	6.49	5.12	7.37
Total cost	19.63	16.86	23.08

[1] All costs and productivities are reported for scheduled machine hours.

5.1.4 Landing Activity

According to the activity sampling, primary transportation was not delayed by loading and manual processing on the landing (Table 23). In the ground-based treatments, the loader and the bucker were idle and waiting for processing of timber for 54% and 47 % of the scheduled operating time, respectively. To improve loading and manual processing efficiency on the landing in the ground-based treatments, another skidder may be employed to reduce the non-productive time. However, 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. A more detailed summary is provided in Appendix 11.

Table 23 Summary of East Twin landing activity sampling

Harvesting system		Ground-based		Cable
Silvicultural treatment		Group selection	Clearcut	Clearcut
			Time (min)	
Skidder/yarder	Delayed	0.00	0.00	0.00
	Productive	60.00	60.00	60.000
Loader	Delayed	32.14	32.67	14.25
	Productive	27.86	27.33	45.75
Bucker	Delayed	31.53	32.00	17.25
	Productive	28.47	28.00	42.75
			Time (%)	
Skidder/yarder	Delayed	0	0	0
	Productive	100	100	100
Loader	Delayed	54	54	24
	Productive	46	46	76
Bucker	Delayed	53	53	29
	Productive	47	47	71

5.1.5 Stand Damage

In the group selection treatment, the residual stand damage was classified by the type of damage and location relation to harvesting infrastructure (Table 24). Seventy seven percent of the total damage was located within 5 meters from the centre of a skid trail while the remaining 23% was located within 5 meters of harvest block boundaries. Using criteria in Pavel (1999), 51 trees along the skid trail, 3 trees in the patch opening and 6 trees at the junction of the openings and skid trails, showed damage considered unacceptable for retention as residual crop tree in the group selection treatment. Only 1 tree along the boundary of the cable portion of the clearcut was considered unacceptable.

Table 24 Stand damage summary for East Twin group selection treatment

Harvesting system	Ground-based				Cable
Silvicultural treatment	Group selection			Clearcut	Clearcut
Feature	Skid trails	Openings	Junctions	Boundary	Boundary
Damage summary					
No. of sampled trees	425	796	83	92	605
No. of injured trees	69	13	8	2	2
% of sampled trees[a]	16.2	1.6	9.6	2.2	0.3
% of residual stand[b]	2.0	0.4	0.2	n/a	n/a
No. injuries/tree	1.2	1.1	1.6	2.0	1.5
Average size					
Width (cm)	17.1	13.1	20.1	14.0	12.0
Length (cm)	45.8	30.1	42.2	23.0	42.0
Area (cm^2)	783.2	393.1	846.3	322.0	504.0
Height (cm)[c]	135.6	82.0	81.2	37.3	125.0
Percent of total damage[d]					
Stem	86.5	100.0	100.0	100.0	100.0
Stem and root	12.1	0.0	0.0	0.0	0.0
Root	0.7	0.0	0.0	0.0	0.0
Crown	0.7	0.0	0.0	0.0	0.0

[a] Sampled trees = sample population
[b] Residual trees = total population – calculated from cruise and harvesting data
[c] Measured from base of tree to middle of damage
[d] Damage classes: Stem – Stem damage only, Stem and root – Stem and root damage combined, Root – Root damage only, and Crown – All crown damage.

5.2 Minnow Creek

5.2.1 Planning and Layout

The planning and layout costs were highest, \$1.73/m^3, in the group selection because of the need to designate removal patches and larger block perimeter (Table 25). The costs were also 1.6 times higher in the group retention than the clearcut due to the need to designate retention patches and a greater block perimeter. As result of not having to designate removal or retention patches, the layout cost was lowest in the ground-based clearcut at \$0.45/m^3.

Table 25 Summary of Minnow planning and layout costs

Silvicultural treatment	Group selection	Group retention	Clearcut
Traverse and boundary cost (\$)	1377.60	1281.77	1078.13
Mapping and office cost (\$)	157.40	146.45	123.18
UNBC group selection layout cost (\$)	750.00	750.00	n/a
Total cost (\$)	2285.00	2178.22	1201.31
Final volume (m^3)[a]	1323.26	1883.62	2657.78
Layout / planning cost (\$/m^3)	1.73	1.16	0.45

[a] Net merchantable volume was provided by the BC MOF

Pre-existing skid trails and a landing from previous harvest units were used when possible. This resulted in decreased landing and skid trail construction costs. During harvesting the closest landing was utilized, often resulting in the same landing being utilized for multiple treatments.

During manual felling, it became clear that marking with colours such as red and greens should be avoided due to colour blindness concerns. The manual feller observed reds as a brown colour, making the marks hard to distinguish from the bark. Upon further research, it was found that roughly 10% of the male population is color blind (Neitz et al, 1989).

5.2.2 Harvesting Operations

5.2.2.1 Felling

Even though mechanical felling, using a Timberjack 618 feller buncher, in the clearcut had the fastest cycle time of 1.35 minutes per tree, production was highest in the group retention treatment due to the greatest merchantable volume per tree (Table 26 and 27; Appendix 12). The second highest production occurred in the group selection, again due to a higher merchantable volume per tree. The clearcut felling cycle time was the shortest but due to the lowest average merchantable volume per tree, the observed mechanical felling cost was \$3.60/m^3. Felling costs were similar to two FERIC studies in the interior of BC due to similar production \$3.44m^3 to \$3.77m^3 (Gillies, 2002) and \$2.71m^3 to \$3.39m^3 (Sambo, 2003). If the volume per tree was standardized for all treatments, 1m^3 per tree, the observed cost would have been lowest in the clearcut, followed by the group retention, and lastly by the group selection at \$3.29/m^3, \$3.45/m^3, and \$3.60/m^3, respectively. This indicates that tree size, and decay percentage can have an effect on felling production cost. During felling, snow was present on the site and repeatedly caused the buncher to slide downhill. In the case of manual felling, the snow had no observable effect on productivity. As manual felling was utilized top fell a proportion of each unit, weighted mechanized and manual felling costs were calculated to determine the contribution of the each felling method to the total felling cost.

Table 26 Cycle time of Minnow mechanized felling phase

Silvicultural treatment	Group selection	Group retention	Clearcut
Average time (min/cycle)			
Total productive time	0.82	0.87	0.87
Total non-productive time	0.59	0.48	0.42
Total cycle time	1.41	1.35	1.29
Average time (%/cycle)			
Total productive time	57.99	64.27	67.54
Total non-productive time	42.01	35.73	32.46
Total cycle time	100.00	100.00	100.00

Table 27 Summary of Minnow mechanized felling costs

Silvicultural treatment	Group selection	Group retention	Clearcut
Average slope (%)	21.04	12.17	28.49
Percent of total trees multicut (%)	3.24	16.81	10.14
Net volume per tree (m^3)[a]	1.05	1.07	0.91
Volume / hour (m^3/hr)[b]	44.85	47.79	42.52
Equipment and labour rate ($/hr)[b]	153.24	153.24	153.24
Observed felling cost ($/$m^3$)[b]	3.42	3.21	3.60
Weighted average felling cost ($/$m^3$)[b]	2.96	3.15	3.22

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF

[b] All costs and productivities are reported for scheduled machine hours

Equation 14 describes the total productive cycle time (delay-free) for a feller buncher, determined from a general linear model analysis. Slope and the use of multiple cuts to fell a tree were significant factors ($P<0.05$), while treatment and tree species were insignificant factors (Table 28).

Table 28 Significance of Minnow independent felling variables to total productive cycle time

Independent variables	P value
Slope	0.000
Tree species	0.964
Skid trail designation	0.457
Treatment	0.664
Multiple cuts	0.000

[14] Total productive cycle time (min) = 1.391 + 0. 006S - 0.785M_0 - 0.110M_1

Where :
S = slope (%)
M_0 = No multiple cuts required (if yes = 1, no = 0)
M_1 = One multiple cut required (if yes = 1, no = 0)

Sample number = 1153 R^2 = 20.3% Standard error of estimate = 0.542

A total of 507 trees were manually felled in the study with the majority being in the clearcut treatment (Table 29). The highest felling cost was observed in the group retention due to the spread-out locations of the trees to be felled. When this cost was weighted for its felling contribution, the overall manual felling cost was lowest in the group retention. The trees in the group retention were manual felled due to tree characteristics where in the group selection and clearcut treatments, tree were being manually felled as a result of both tree characteristics and steep slopes. It should be noted that the feller employed was colour blind and had problems seeing reds, the colour used to mark trees for removal in the group selection treatment. In the future, such marking should be colour blind friendly, reds and greens should be avoided.

Table 29 Summary of Minnow manual felling costs

Silvicultural treatment	Group selection	Group retention	Clearcut
Time (hrs)	10.25	2.50	14.00
Trees felled (No)	168	34	305
Net volume per tree (m^3)[a]	1.05	1.07	0.91
Feller cost ($/hr)	50.00	50.00	50.00
Observed felling cost ($/$m^3$)[b]	2.90	3.43	2.52
Weighted average felling cost ($/$m^3$)[b]	0.39	0.07	0.26

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[b] All costs and productivities are reported for scheduled machine hours

5.2.2.2 Skidding

Ground-based skidding techniques were used for all treatment units. Cycle time data for the John Deere 748E grapple skidder is displayed in Table 30 for all three treatments. A more complete summary of the skidding cycle elements is given in Appendix 13. As mentioned, both feller bunching and hoe chucking were utilized to group logs for greater grapple skidder efficiency.

Table 30 Cycle time of Minnow ground-based skidding phase

Silvicultural treatment	Group selection	Group retention	Clearcut
Average time (min/cycle)			
Total productive time	8.63	7.27	11.07
Total non-productive time	4.51	1.72	3.39
Total cycle time	13.14	8.99	14.47
Average time (%/cycle)			
Total productive time	65.67	80.89	76.56
Total non-productive time	34.33	19.11	23.44
Total cycle time	100.00	100.00	100.00

The highest productivity was observed in the group retention treatment due to gentle slopes and a shorter average skidding distance equivalent to half of the average skidding distances in the group selection and clearcut treatments (Table 31). While a greater number of logs per cycle were delivered to the landing in the clearcut, a lower average volume per log and greater cycle time still resulted in it having the lowest productivity and highest costs. Studies by Hedin and DeLong (1993) and Kellogg et al (1991) also found that m3/log and number of logs/turn had a significant impact on harvesting cost.

Table 31 Summary of Minnow skidding production and costs

Silvicultural treatment	Group selection	Group retention	Clearcut
Average pieces/cycle (no.)	4.83	4.60	5.63
Average slope (%)	15.5	13.4	27.2
Average turn length (m)	26.2	28.3	25.0
Average distance loaded (m)	246.8	133.9	273.7
Average distance empty (m)	246.8	133.9	289.3
Turns hoe chucked (%)	20.18	0	25.58
Net volume per tree (m^3)[a]	1.05	1.07	0.91
Volume / turn (m^3)[a]	5.09	4.94	5.13
Volume / hour (m^3/hr)[b]	23.25	32.95	21.29
Equipment and labour rate ($/hr)	116.26	116.26	116.26
Skidding cost ($/$m^3$)[b]	5.00	3.53	5.46

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[b] All costs and productivities are reported for scheduled machine hours

Figure 5 illustrates the proportion each delay that constitutes the non-productive time. The group selection had the greatest amount of non-productive time per cycle at 4.51 min/turn followed by the clearcut and group retention at 3.39 min/turn and 1.72 min/turn, respectively. The largest delay observed in all three treatments occurred in the group selection and was due to a sheared blade pin on the skidder. This delay accounted for 11.9% of the total cycle time, and if it had not occurred, skidding in the group selection would have had a cost of \$4.41/m^3, reducing the cost by \$0.59/m^3.

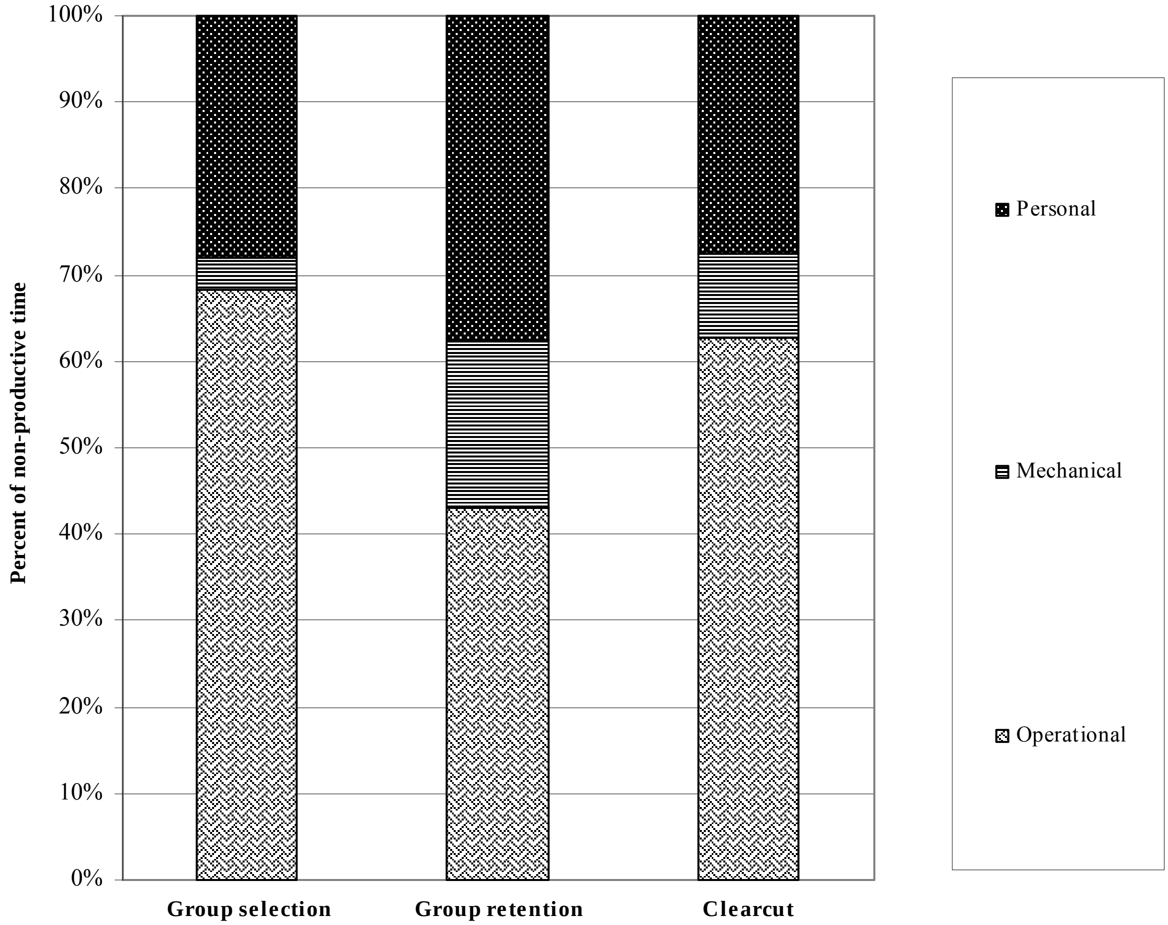

Figure 5 Summary of Minnow non-productive timing elements for skidding

Through a general linear model analysis, the delay-free total productive time was significantly affected by the following factors: average skidding distance, number of logs per turn, maximum length of logs skidded, slope, and treatment (Table 32). The use of hoe chucking or skid trail designation did not have a significant effect.

Table 32 Significance of Minnow independent skidding variables to total productive cycle time

Independent variables	P value
Distance	0.000
Logs skidded	0.000
Maximum length of skidded logs	0.000
Skid trail designation	0.866
Slope	0.001
Treatment	0.000
Hoe chucked wood	0.289

Equation 15 describes the total productive cycle time (delay-free) for a grapple skidder, determined from a general linear model analysis. A significant linear relationship was found between total productive time, treatment, distance, slope, maximum length of logs in a turn, and number of logs per turn.

[15] Total productive cycle time (min) = 0.278 + 0. 017D + 0.316Lg + 0.103Ln + 0.027S - 0.647Gs - 0.086Gr

Where :
D = Distance skidded (m)
Lg = Number of logs
Ln = Maximum length logs in a turn (m)
S = Slope (%)
Gs = Group selection treatment (if yes = 1, no = 0)
Gr = Group retention treatment (if yes = 1, no = 0)

Sample number = 1066 R^2 = 62.9% Standard error of estimate = 2.60

5.2.2.3 Hoe Chucking

Hoe chucking was only required in the group selection and clearcut treatments and had an observed cost of \$6.34/m^3 and \$4.67/m^3, respectively. When these costs are weighted by contribution, these costs were \$1.02/m^3 for the group selection and \$1.17/m^3 for the clearcut treatment.

Table 33 Minnow shift level summary for hoe chucking

Silvicultural treatment	Group selection	Group retention	Clearcut
Time (hrs)	13	0	30
Equipment and labour rate (\$/hr)[b]	103.48	103.48	103.48
Trees hoe chucked	202	0	730
Net volume per tree (m^3)[a]	1.05	1.07	0.91
Volume hoe chucked (m^3)	212.10	0.00	664.30
Observed hoe chucking cost (\$/m^3)[b]	6.34	0.00	4.67
Weighted average hoe chucking cost (\$/m^3)[b]	1.02	0.00	1.17

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[b] All costs and productivities are reported for scheduled machine hours

5.2.2.4 Processing

Processing for all treatments was completed manually. The primary consideration of processing was to maximize commercially valuable wood recovery. The priorities were as follows: peelers, saw logs, post and rail wood, and finally pulpwood. The minimum requirements of a peeler are as follows: > 75% sound wood of either spruce or subalpine fir, with the sound wood being > 20.3cm (8in) in diameter, a minimum length of 5.3m (17ft 4in) to 15.8m (51ft 9in) in length. In order to be suitable for a saw log, 50% of the wood has to be sound with the sound wood being a minimum of 10cm (4in) of sound wood. All species except hemlock on site were suitable for the production of saw logs as the trucking costs of hemlock to the nearest processing facilities were prohibitive. The minimum required length for saw logs was 3.7m (12ft) to a maximum length of 15.8m (51ft 9in). In the case of cedar, these logs will be processed into small dimension aesthetic lumber. Cedar was also processed into post and rail timber which required a minimum 7.5cm (3in) shell of clear solid wood and length of 2.5m (8ft 3in) to 15.8m (51ft 9in). The combined decay, waste, and breakage estimates for the group selection, group retention, and clearcut treatments were

55%, 53%, and 68%, respectively. Identical processing techniques were used in Minnow as East Twin.

The treatment with the lowest processing cost was the group retention followed by the group selection and clearcut. This might be the result of the group retention having the lowest decay waste and breakage rates and the higher proportion of spruce and subalpine fir (Table 34 and 35). The hemlock, spruce, and subalpine fir on site had less decay, thus was faster to process.

Table 34 Minnow shift level summary for manual processing

Silvicultural treatment	Group selection	Group retention	Clearcut
Time (hrs)	57	79	128
Trees processed (no.)	1256	1756	2916
Gross volume per tree (m^3)[a]	2.35	2.29	2.85
Net. Volume per tree (m^3)[b]	1.05	1.07	0.91
Cost ($\$/m^3$)[c]	1.08	1.05	1.21

[a] Provided by the BC MOF Cruise report.
[b] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[c] All costs and productivities are reported for scheduled machine hours.

Table 35 Minnow species volumes for each treatment[1]

Silvicultural treatment	Group selection	Group retention	Clearcut
Volume (m^3)[a]			
Cedar – saw logs	369.6 (27.9)	457.5 (24.3)	925.9 (34.8)
Cedar – post & rail	405.8 (30.7)	385.0 (20.4)	646.0 (24.3)
Spruce and subalpine fir – dry logs, saw logs, and peelers	515.8 (39.0)	1019.3 (54.1)	1073.4 (40.4)
Hemlock – pulp	32.0 (2.4)	21.8 (1.2)	12.4 (0.5)
Total	1323.3 (100.0)	1883.6 (100.0)	2657.8(100.0)

[1] Values in ( ) indicate % of the total volume.
[a] Net merchantable volume was provided by the BC MOF

Several improvements can be made in the felling of trees that can improve the efficiency of the bucker. These include manual felling larger trees regardless of species to minimize butt shatter and stump pull and when using multiple cuts during mechanical felling, cuts should be matched to ensure a level flat cut on the bottom log.

5.2.2.5 Loading

The timber on this site was sorted into six product categories: dry spruce, spruce and subalpine fir peelers, spruce and subalpine fir saw logs, cedar saw logs, cedar post and rail timber, and hemlock pulp. As a result of these multiple sorts, landing space became an issue on landing 2 as it was the smallest of the three landings measuring 50 m by 50 m while landing 1, a pre-existing landing, measured 150 m by 50 m, and landing 3 measured 80 m by 40 m. This effect can be observed in the loading costs below as the group selection treatment primarily used landing 2 and had the highest loading cost at \$4.75/m^3 compared to the group retention and clearcut which had costs of \$4.44/m^3 and \$4.18/m^3 respectively (Table 36). In the group selection treatment, the loading cost was increased by a greater amount of unproductive time due to delays and lack of wood to process (Table 41).

Table 36 Minnow shift level summary for loading

Silvicultural treatment	Group selection	Group retention	Clearcut
Volume per tree (m^3)[a]	1.07	1.05	0.91
Volume processed (m^3/hr)[b]	19.36	20.7	22.03
Equipment and labour rate (\$/hr)[b]	91.97	91.97	91.97
Cost (\$/m^3)[b]	4.75	4.44	4.18

[a] Net merchantable volume per tree was calculated from the provided merchantable volumes from the BC MOF
[b] All costs and productivities are reported for scheduled machine hours

5.2.2.6 Other Harvesting Costs

Equipment moving cost and skid trail and landing construction costs should be considered as part of the final cost (Table 37 and 38). The group retention treatment required 24 hours of landing and skid trail construction, compared to 55 and 71 hours for the group retention and clearcut units due to minimal upgrade in the existing harvesting infrastructure to bring it up to legislative standards. This was also true for over half of the skid trails required in the group selection; however a landing had to be constructed so that skidding costs would be reduced. The clearcut required both the construction of skid trails and a landing, and as a result had the greatest amount of hours spent in constructing these features. As the costs are dependent on the volume of timber removed, the costs are lower in the clearcut versus the group selection as more volume was removed from the same amount of area. The group retention had the lowest costs as the features were already pre-existing. As skid trails and landings were pre-existing in some of the treatments, these results will not be included in the comparison of harvesting costs between treatments.

Table 37 Summary of Minnow Twin equipment moving costs

Silvicultural treatment	Group selection	Group retention	Clearcut
Move in and out cost ($)	676.90	963.54	1359.56
Final net volume (m^3)[a]	1323.26	1883.62	2657.78
Cost ($/$m^3$)	0.51	0.51	0.51

[a] Net merchantable volume was provided by the BC MOF

Table 38 Summary of Minnow skid trail and landing construction costs

Silvicultural treatment	Group selection	Group retention	Clearcut
Time - excavator (hrs)[a]	31.00	9.00	38.50
Excavator and labour cost ($/hr)[a]	103.48	103.48	103.48
Time - bulldozer (hrs)[a]	24.00	15.00	32.50
Bulldozer and labour cost ($/hr)[a]	111.78	111.78	111.78
Total costs ($)[a]	5890.51	2608.01	7616.73
Final volume (m^3)[b]	1323.26	1883.62	2657.78
Cost ($/$m^3$)[a]	4.45	1.38	2.87

[a] All costs and productivities are reported for scheduled machine hours.
[b] Net merchantable volume was provided by the BC MOF

5.2.3 Summary of Harvesting Costs

The unit cost ($/$m^3$) was lowest in the group retention treatment, $13.45/$m^3$, as a result of having the shortest average skidding distance, gentle slope, no hoe chucking, less manual felling, and a higher volume of merchantable timber extracted per tree. The increased volume is the result of more non-cedar species being present. These species have a lower level of defect than cedar on this site and this lower defect level allowed the bucker to process the logs without making multiple cuts, thus increasing productivity and efficiency. The clearcut had the second highest cost at $16.33/$m^3$ due to a longer skidding distance, steeper slopes, and lower merchantable volume per extracted tree than in the group retention.

Table 39 Summary of Minnow total costs ($/$m^3$)[1]

Silvicultural treatment	Group selection	Group retention	Clearcut
Layout/planning	1.73	1.16	0.45
Felling[a]	3.35	3.21	3.49
Skidding	5.00	3.53	5.46
Hoe chucking	1.02	0.00	1.17
Processing	1.08	1.05	1.21
Loading	4.75	4.44	4.18
Total cost	16.93	13.39	15.96

[1] All costs and productivities are reported for scheduled machine hours.
[a] Combined weighted average costs of manual and mechanized felling

The highest costs were observed in the group selection treatment as a result of having steep slope conditions and long skidding distances similar to that of the clearcut while having the added constraints to skidding and felling as a result of treatment. These constraints caused mechanical delay for the skidder and resulted in the feller buncher becoming high centred on an existing log. In addition the planning and layout costs were highest, $\$1.73/m^3$, in the group selection because of the need to designate removal patches and skid trails compared to the group retention, where retention patches and skid trails were easy to mark due to gentle terrain, and the clearcut, where only the boundary and main skid trail were laid out and marked.

The results and discussion presented here were based upon treatment units ranging in size from 3.6 ha to 7.4 ha. According to the final volume data, the merchantable volume per hectare is greater in the group retention treatment than in the other treatments due to a slightly lower defect percentage, 53% versus 55% in the group selection and 68% in the clearcut treatment. This defect variation results in a merchantable volume differences between the treatments. As a result of this higher merchantable volume, the group retention treatment has lower planning and layout, felling, skidding, processing, and loading costs than the group selection or clearcut.

If the merchantable volume per tree was standardized ($1m^3$/tree) in each treatment and the number of harvested trees in each treatment remained constant, the group retention harvesting system would cost $\$14.33/m^3$ due to a decrease in merchantable volume per piece (Table 40). This is an increase of $\$0.88/m^3$. The group selection costs would also increase by $0.99/m^3 to $18.38/m^3 as a result of a decrease in merchantable volume per piece. The cost of the clearcut unit would decrease by $1.45/m^3 due to an increase in average piece size of 0.09m^3. The group selection and clearcut costs would also decrease by $1.07/m^3 and $1.06/m^3, respectively if slopes had not required the use of an excavator for hoe chucking. Skidding costs would decrease by 25% if the average skidding distances in the clearcut and group selection treatments was the same as that in the group retention.

Table 40 Summary of Minnow total costs ($/m^3) given a standardized merchantable volume per stem of 1m^3 [1]

Silvicultural treatment	Group selection	Group retention	Clearcut
Layout/planning	1.82	1.24	0.41
Felling [a]	3.19	3.00	3.83
Skidding	5.27	3.78	4.98
Hoe chucking	1.07	0.00	1.06
Processing	1.13	1.13	1.10
Loading	5.08	4.67	3.80
Total cost	17.56	13.82	15.18

[1] All costs and productivities are reported for scheduled machine hours.
[a] Combined weighted average costs of manual and mechanized felling

5.2.4 Landing Activity

According to the activity sampling, primary transportation was delayed by loading and manual processing on the landing 3.8% to 9.1% of the scheduled operating time (Table 41 and Appendix 14). These delays resulted in the skidding cost being increased not only for the skidder but also for the loader and bucker as less wood was available for processing, sorting, and loading over the same period of time, than if no delays were to occur. The skidding delay on the landing can easily be avoided through better communication and coordination of activities. In the different treatments, the bucker was waiting for timber to process 13% to 33% of the scheduled operating time. The loader was waiting less time for timber to process, 3% to 12% of the scheduled operating time, as other tasks such as loading trucks or clearing slash or debris could be completed after sorting and decking was completed. The implementation of another skidder on the sites would increase manual processing and loading efficiency by a minimum of 3% but would cause a greater increase in the skidder delay time due to the harvesting components becoming largely unbalanced.

Table 41 Summary of Minnow landing activity sampling

Silvicultural treatment		Group selection	Group retention	Clearcut
			Time (min)	
Skidder	Delayed	2.31	2.62	5.44
	Productive	57.69	57.38	54.56
Loader	Delayed	18.15	12.62	15.41
	Productive	41.85	47.38	44.59
Bucker	Delayed	28.15	19.54	28.64
	Productive	32.15	40.46	31.36
			Time (%)	
Skidder/yarder	Delayed	4	4	9
	Productive	96	94	91
Loader	Delayed	30	21	26
	Productive	70	79	74
Bucker	Delayed	46	33	48
	Productive	53	67	52

5.2.5 Stand Damage

There is no significant difference in the amount of stand damage between the three treatments (Table 42). Stand damage in all treatments was found within 5 meters of harvest features. The skid trails were dominated by skid trail creation and skidding origin stand damage, or stem and root type damage. Damage on patch, block and opening boundaries was a combination of both skidding and mechanical felling damage, or stem and crown type damage. In the majority of cases, the boundary damage (openings, patch and block boundaries) could have been avoided through better placement of bunches or improved felling practices in regards to swinging. It was a common practice by the buncher operator to place bunches of timber outside or on the edge of the boundary resulting in timber outside of the harvest area being damaged if not by the felled trees placement then by the removal of those bunches by the skidder. Stem damage on the skid trails occurred at the funnel points in the boundary or on the downhill side of a skid trail when the trail was not level. This could easily be avoided through either the creation of level skid trails or the use of artificial tree protection such as rub logs on the side of the skid trails or the use of rub trees which are removed after harvest. Increased damage was also found on skid trail corners and thus these corners should be placed in harvest patches to provide extra area for the timber to swing. According to Pavel (1999), in the group selection treatment 14 trees along the skid trail, 18 trees in the patch opening and 14 trees at the meeting of the two features would not be considered acceptable residual crop tree while 17 trees on the block boundary and 4 patch boundary trees in the group retention treatment and 13 trees along the clearcut were considered unacceptable.

Table 42 Minnow stand damage summary

Silvicultural treatment	Group selection			Group retention		Clearcut
Feature	Skid trails	Openings	Both	Block boundary	Patch boundary	Boundary
Damage summary						
No. of sampled trees	539	985	218	538	534	753
No. of injured trees	25	34	21	26	17	26
% of sampled trees[a]	4.6	3.5	9.6	4.8	3.2	3.5
% of residual stand[b]	0.9	1.3	0.8	n/a	1.3	n/a
No. injuries/tree	1.9	1.1	2.0	2.2	1.9	1.6
Average size						
Width (cm)	13.8	15.5	15.3	12.9	10.6	14.8
Length (cm)	34.6	39.9	42.3	41.7	22.2	42.8
Area (cm^2)	538.1	675.4	843.0	668.7	250.6	859.1
Height (cm)[c]	103.6	124.5	140.5	307.3	178.9	248.5
Percent of total damage[d]						
Stem	88.0	94.1	100	93.2	93.3	90.5
Stem and root	12.0	4.9	0	0	0	0
Root	0	0	0	0	0	0
Crown	0	0	0	6.8	6.7	9.5

[a] Sampled trees = sample population
[b] Residual trees = total population – calculated from cruise and harvesting data
[c] Measured from base of tree to middle of damage
[d] Damage classes: Stem – Stem damage only, Stem and root – Stem and root damage combined,
Root – Root damage only, and Crown – All crown damage.

5.3 General Discussion

5.3.1 Planning and layout

As expected the lowest planning and layout costs were observed in the ground-based clearcuts, followed by the cable clearcut, group retention treatment, and finally group selection treatments (Table 5, 25 and 43). The need for deflection line in the cable treatment made it more expensive than a ground-based clearcut. In the group retention, higher layout costs than a ground-based clearcut was due to the need to mark the leave tree patches and cruise requirements. The layout in the group selection treatments was the most expensive in both locations due to the need to designate and mark patches, skid trail locations and greater block perimeters than in the other treatments. In hindsight, only the outer edge of selection or retention patches could have been marked, reducing the layout costs. Marking colours should be "colour blind" friendly as roughly 10% of the male population is color blind (Neitz et al, 1989), this will ensure appropriate trees are retained or removed. Colours such as red and greens should be avoided. The layout costs were lower for the group selection treatment in Minnow over that of East Twin. This may be attributed to the increased experience of the crew, having implemented the layout after observing the harvesting of East Twin.

Table 43 Planning and layout costs per hectare[1]

Location	East Twin			Minnow		
Harvesting system	Ground-based		Cable	Ground-based		
Silvicultural treatment	Group selection	Clearcut	Clearcut	Group selection	Group retention	Clearcut
Total cost ($)	1923.75	245.31	2045.74	2285	2178.22	1201.31
Treatment area (ha)[1]	8.7	1.1	6.7	11.2	10.7	7.4
Harvested area (ha)[1]	2.1	1.1	6.7	3.6	6.1	7.4
Treatment area ($/ha)	221.12	223.01	305.33	204.02	203.57	162.34
Harvested area ($/ha)	916.07	223.01	305.33	634.72	357.09	162.34

[1]Harvest and treatment area provided by the BC MOF Cruise reports

Sensitivity analysis showed that tree size expressed as merchantable volume has a large effect on planning and layout costs (Figure 6). Planning and layout costs in the group selection at East Twin would have been 1.6 times higher if the merchantable volume per tree was the same as in the clearcut at Minnow. In addition, maximizing the commercial volume per stem can also reduce the total costs.

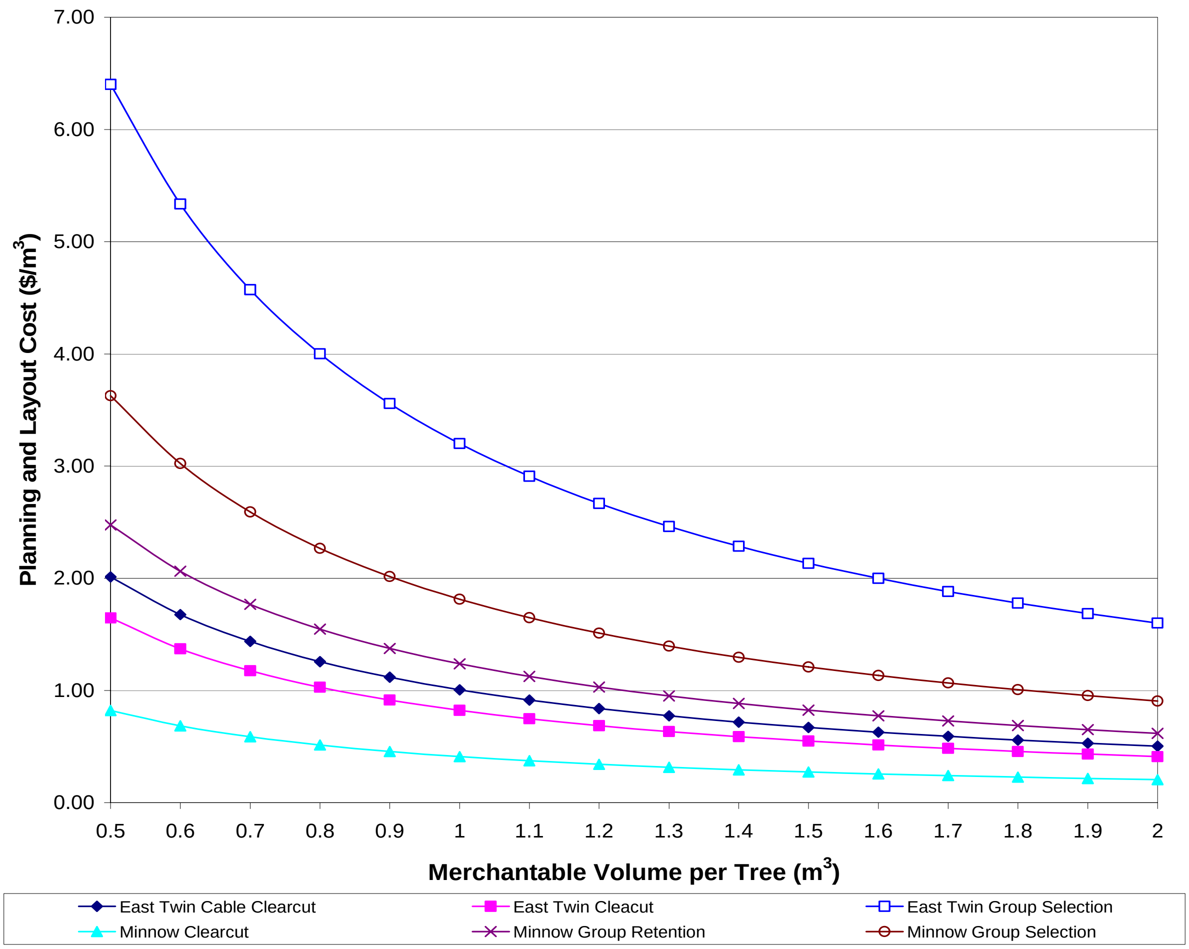

Figure 6 Sensitivity analysis of planning and layout costs versus merchantable volume per tree

5.3.2 Felling

In all but one case, the Minnow group retention treatment, manual felling resulted in the lowest cost ($\$/m^3$) as result of high hourly production (Table 7, 27, and 29; Figure 7). While mechanized felling was utilized at Minnow, manual felling was utilized to fell trees on steeper slopes (>35%), due to limited traction, and for large solid spruce trees, as multiple cuts and pushing would have resulted in unnecessary stump pull and butt shatter. As such, observed manual felling costs in Minnow were higher than those in East Twin due to the spread-out locations of the trees to be felled; this was especially the case for the Minnow group retention treatment. While mechanized felling costs were slightly greater, safety was improved as increased butt flare in cedar in combination with butt rot can make directional felling difficult and at times dangerous. In addition, mechanized felling resulted in increased skidding productivity (Table 11 and 31).

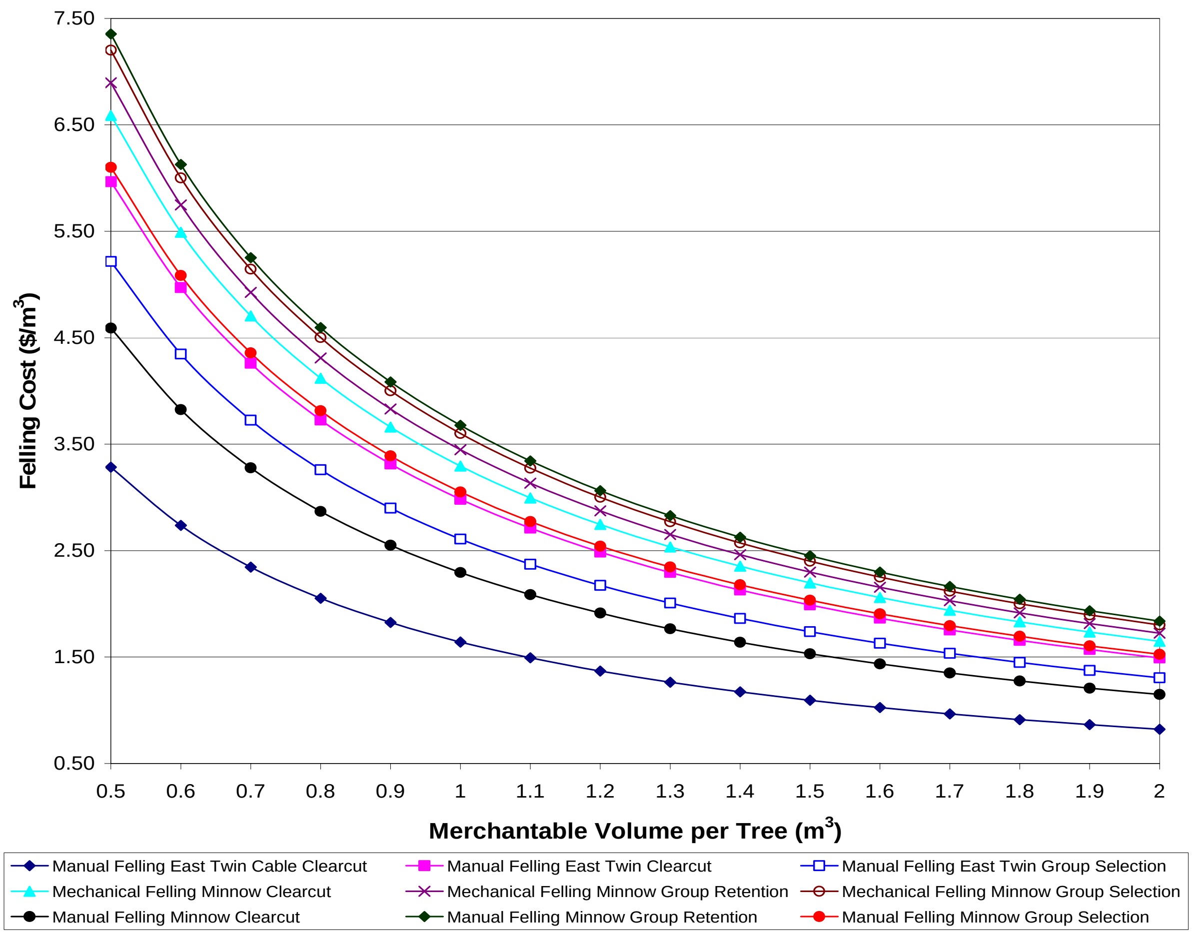

Figure 7 Sensitivity analysis of observed felling costs versus merchantable volume per tree

Significant variables that affected delay-free cycle time for mechanical and manual felling varied (α=0.05; Table 8 and 28). While skid trail designation, tree species and treatment had an effect on the total productive time for manual felling at East Twin, they had no significant effect on mechanized felling at Minnow. The reverse can be said about slope and multiple cuts. Because tree diameter measurements were only collected for the cable clearcut treatment, as a result of safety and manpower constraints, the contribution of tree diameter to felling productivity is limited to the cable treatment; however, we suspect that the observation will also be true for other treatments. In the case of the mechanized felling, the effect of diameter may play a lesser role as the actual cutting times only varied from 1.2 to 34.2 seconds, averaging 6.1 seconds per tree while in the manual felling treatments cutting times varied from 3.0 to 290.4 seconds averaging 60.3 seconds.

5.3.3 Primary Transportation

5.3.3.1 Skidding

Skidding productivity was greatest in the Minnow treatments (Table 11 and 31), however due to high ownership costs of the grapple skidder at Minnow, the East Twin treatments had lower costs with the exception of the Minnow group retention treatment. Higher productivity in the Minnow group retention treatment was due to the low skidding distance and gentle slope. A given a standard merchantable volume per tree, the grapple skidder had a lower cost than line skidder even with a higher hourly cost (Figure 8). Given a standardized skidding distance and merchantable volume per stem, the grapple skidder was still the most cost effective (Table 44). The East Twin clearcut had a higher standardized cost due to proportionally higher travel times than that of the East Twin group selection and a greater cubic meter per piece.

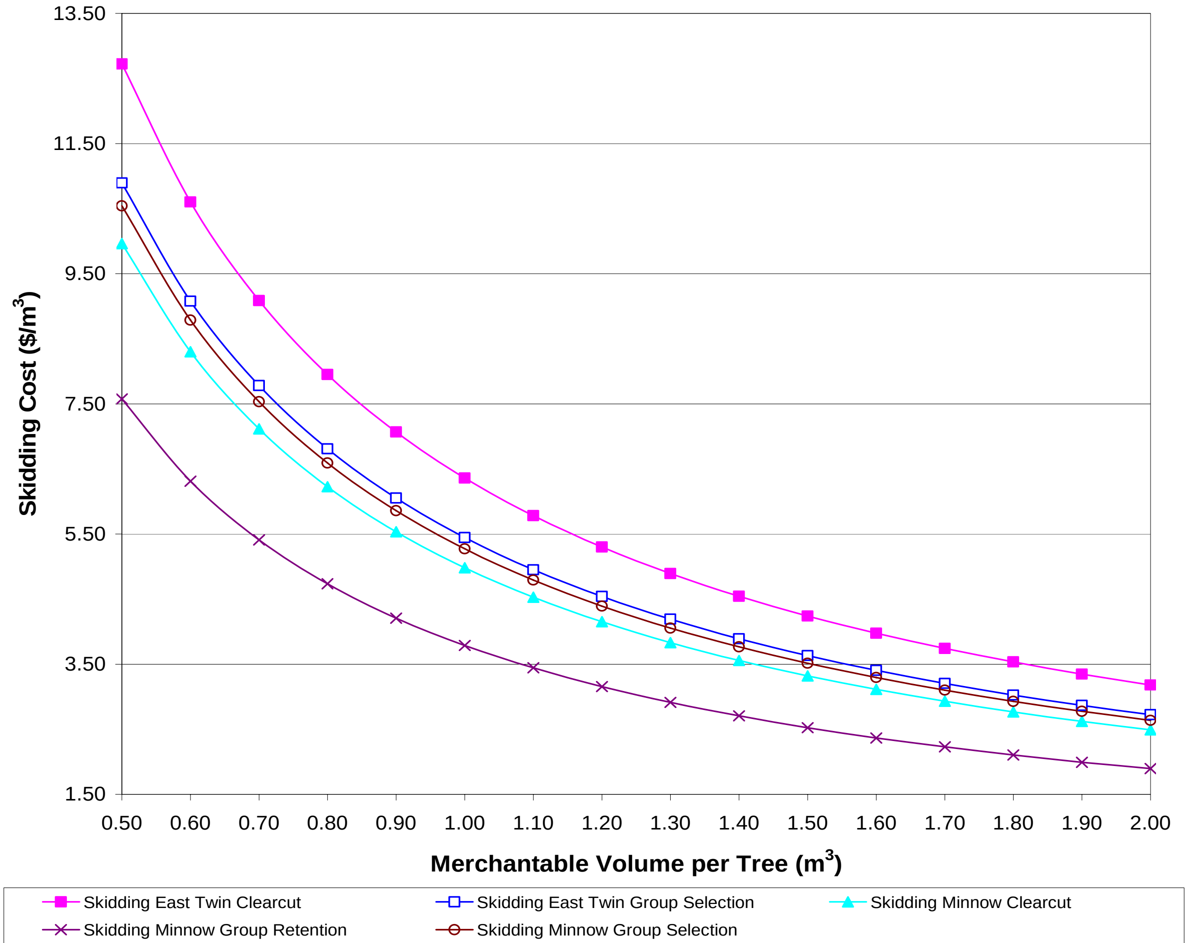

Figure 8 Sensitivity analysis of skidding costs versus merchantable volume per tree

Table 44 Skidding costs given a standardized skidding distance of 100 meters and merchantable volume per stem of 1m³ [1]

Location	East Twin		Minnow		
Equipment utilized	Line skidder		Grapple skidder		
Silvicultural treatment	Group selection	Clearcut	Group selection	Group retention	Clearcut
Net. volume per turn (m^3)	5.86	4.35	4.83	4.60	5.63
Total cycle time (min)	17.86	16.87	10.21	8.34	10.45
Volume / hour (m^3/hr)	19.69	15.47	28.38	33.09	32.33
Hourly cost ($/hr)	89.74	89.74	116.26	116.26	116.26
Skidding cost ($/$m^3$)	4.56	5.80	4.10	3.51	3.60

[1] All costs are reported for scheduled machine hours.

Unlike with felling, the significant variables that affected delay-free cycle time for both grapple and line skidding varied little (Table 12 and 32). Slope did not play a significant role in line skidded treatments while it had a significant impact on grapple skidder cycle time. Skid trail designation did not have a significant effect on either skidding method.

5.3.3.2 Yarding

As expected a cable harvesting system was the most expensive method of primary transportation used to harvest a clearcut treatment (Table 11, 14, and 31). This cost difference ($2.28/$m^3$) between Minnow clearcut and the East Twin cable unit was due to dissimilarity in tree piece size. With a standardized piece size of 1m^3 the yarding cost climbs to $11.37/$m^3$ and the difference grows to $6.39/$m^3$ (Figure 9).

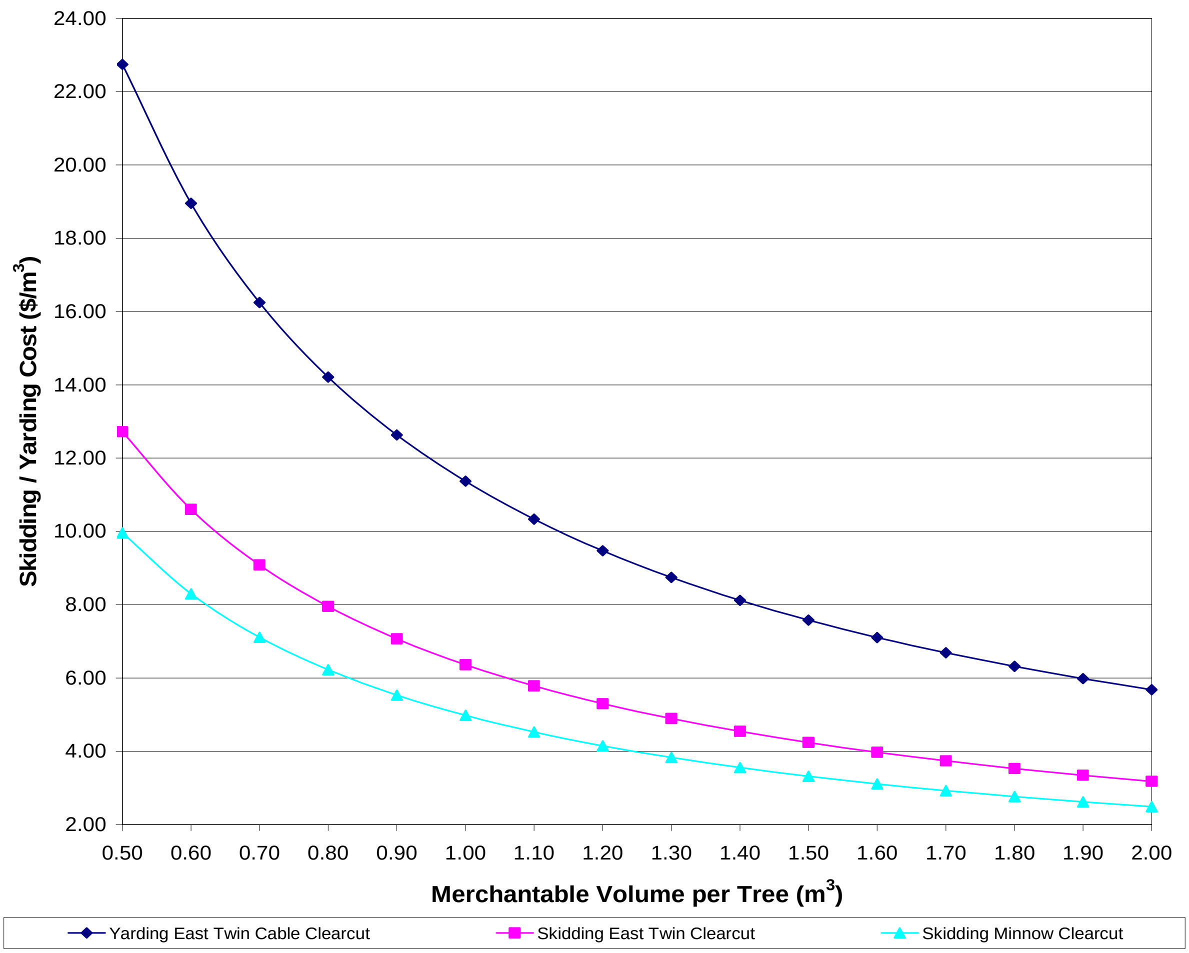

Figure 9 Sensitivity analysis of clearcut yarding and skidding costs versus merchantable volume per tree

The independent variables that affect yarding cycle time are similar to those of the skidder treatments (Table 12, 15 and 32). Yarding distance and number of logs yarded had an impact on cycle time while similar to the East Twin ground-based units, slope had an insignificant effect.

5.3.4 Processing

Processing for all sites was manually completed using a chainsaw at the landing. The primary consideration was to maximize value. Balanced harvest components allowed for the

Minnow group selection and retention units to have the lowest processing costs (Table 16, 24, 34, and 41). A standard piece size of 1m^3 intensifies this result (Figure 10).

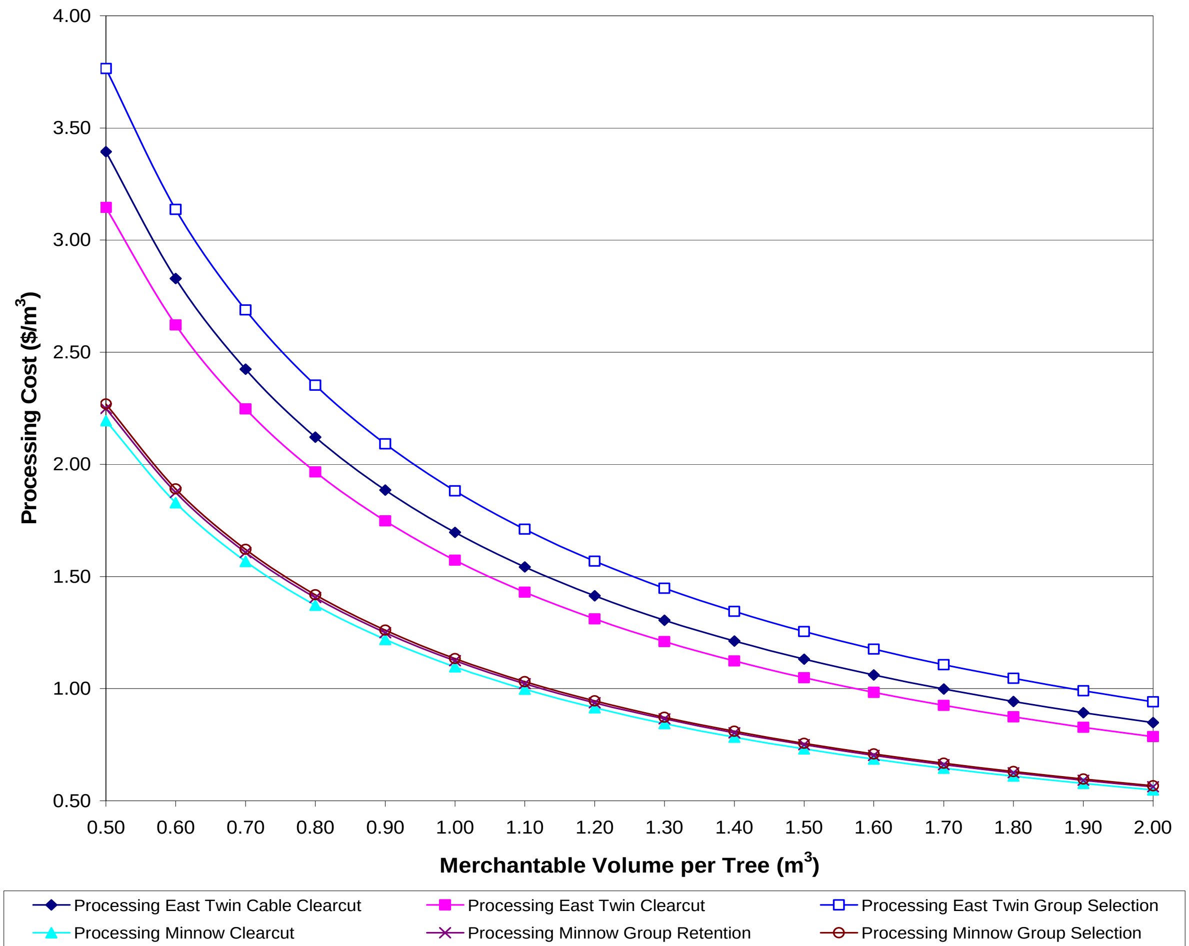

Figure 10 Sensitivity analysis of processing costs versus merchantable volume per tree

Processing over mature western red cedar presents a number of challenges. This species is known for pocket and butt rot and as such requires extra steps be taken during manual processing. During processing, multiple cuts at 0.75m intervals were required to determine where the timber was commercially valuable. As increased merchantable volume decreased the cost, it was important to process the cedar for saw logs and post and rail timber. In the East Twin group selection treatment, additional processing of cedar for post and rail timber could have increased the merchantable volume by as much as 0.60 m^3/ tree, dropping the processing costs by \$0.51/m^3 and resulting in a total harvesting cost of \$10.78/m^3. Hemlock, spruce, and subalpine fir generally did not have any decay, thus was faster to process for the bucker.

Figure 11 Pocket and ring rot in western red cedar

5.3.5 Loading

Loading costs appear to be independent of treatment and more dependent on a balanced harvesting operation and volume per tree (Table 23 and 41). The Minnow treatments had the loader being productive on the landing 69.7% to 79.0% of the time while on the East Twin treatments, the front-end wheel loader was only productive 46.7% to 47.5% of the time. The hydraulic loader was productive 71.3% of the time for the cable treatment but due to higher ownership costs had a higher cost per m^3 (Table 18 and 36). When standardized to a uniform piece size, the Minnow treatments have the lowest loading costs followed by the East Twin ground-based treatments and finally the cable unit (Figure 12).

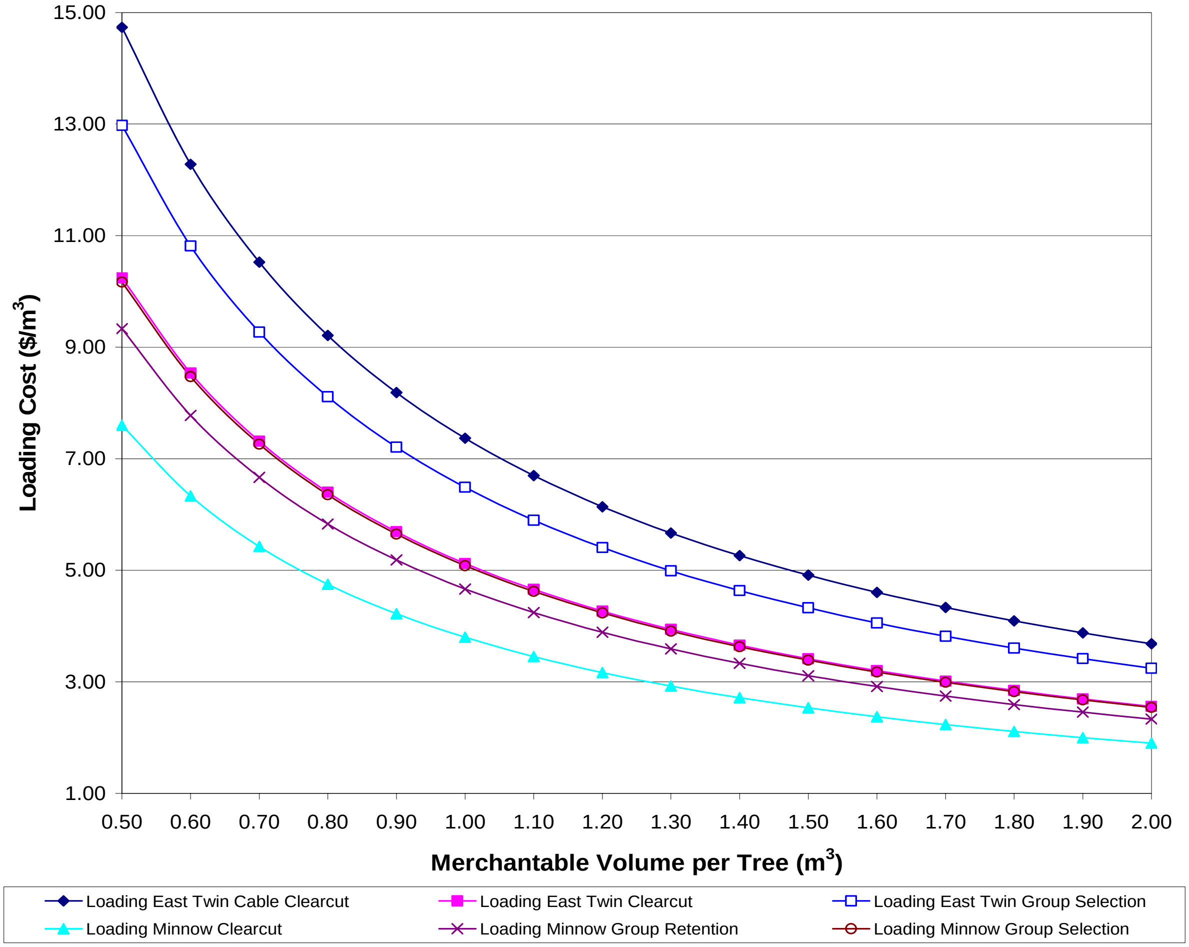

Figure 12 Sensitivity analysis of loading costs versus merchantable volume per tree

5.3.6 Summary of Harvesting Costs

Treatment, machinery utilized, skidding/yarding distance, yarding road changes, and the balance of operations can all affect harvesting costs, however net merchantable volume per tree can have also have an affect (Ashe, 1916; Lynford, 1934; Mann and Mifflin, 1979; Kluender et al., 1997). Once the merchantable volume per piece is standardized, the harvesting costs with a semi-mechanized system have a lower cost than that of a conventional system for the same treatment type (Figure 13). Besides additional layout requirements, the group retention treatment had harvesting costs similar to that of a clearcut. This was expected as the retention treatment had patch spacing that was at two tree lengths apart and as a result had little or no effect on felling or skidding productivity. The cable clearcut had the highest harvesting cost.

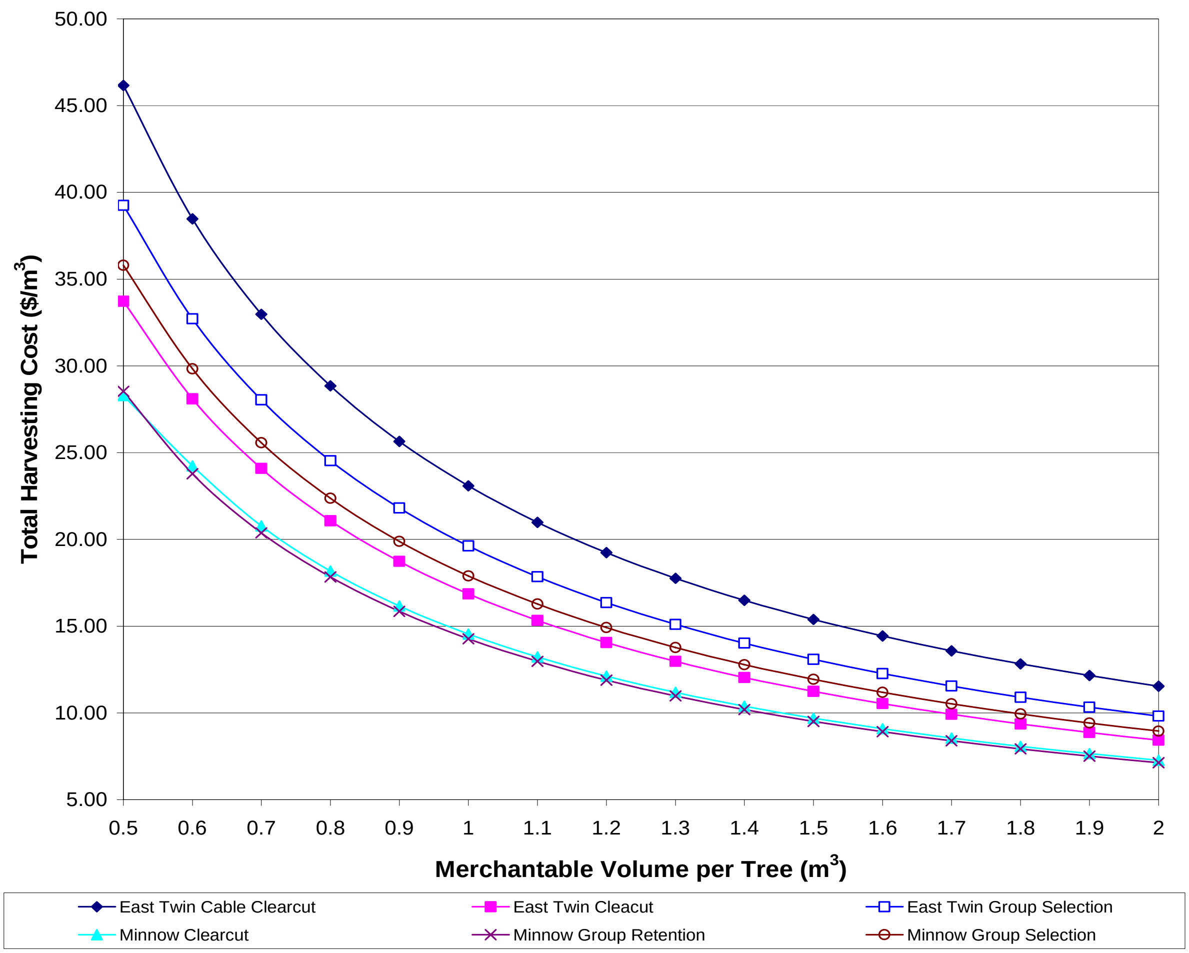

Figure 13 Sensitivity analysis of total harvesting costs versus merchantable volume per tree

5.3.7 Stand Damage

Stand damage in the East Twin clearcut units was minimal and the damage present was on the lower portion of the stem, signifying skidding/yarding damage (Table 24). This reduced felling damage was the result of the felling and skidding/yarding practices utilized, trees were felled downhill or into openings and top choked. In the Minnow treatments trees were felled uphill and bunched into groups to facilitate the use of a grapple skidder. This resulted in increased felling and skidding damage on boundary features (Table 42). On site observations confirmed this while it was noted that felled trees rubbed against the residuals while swinging the feller buncher. This was confirmed by damage being located higher on the stem than possible from skidding. This damage could have been reduced by changing feller buncher swinging and felling practices and occasionally top skidding.

As expected, stand damage was greatest along skid trails or at the opening of harvest patches. In the case of the East Twin group selection treatment this damage was partially the result of the creation of bladed skid trails and two sharp corners. While damage could be decreased through the use of rub structures or an incentive program, (Bennett, 1993; McNeel and Dodd, 1996; Langeson, 1997; Matzka, 1998; Kosicki, 2000a) damage could also be reduced by laying out skid trails as straight and flat as possible and placing skid trail corners within harvest features. This would not only remove the costs of these rub features but likely improve skidding cycle times and thus productivity.

While stand damage did occur in all treatments, as the timber in the treatments is already over mature and contains but and pocket rot, the introduction of pathogens is negligible to fibre quality or mortality. In all cases damage to the stem was also not severe enough to result in mortality. There was a concern regarding wind firmness and corresponding safety in several cases as the result of root damage from the creation of bladed trails, yet two years after harvest, all trees with root damage were still standing. Stand damage to remaining timber and to block boundaries over and above approved limits may result in penalties or prosecution (BC Ministry of Forests and Range, 2002).

5.3.8 Operational Implications

According to the study results, a ground-based group retention treatment can be as cost effective as a ground-based clearcut. This is as expected as the group retention treatment is operationally similar to a clearcut with reserves. Group selection units still continue to be more costly to harvest than even cable units. An opportunity cost of the timber that is left behind in reserves in partial cutting must be considered, however without partial cutting access to timber lands may be reduced, resulting in an increased opportunity cost. Partial cutting will provide long term access to fibre on crown lands in the Robson Valley that will be maintained if not improved over current levels. The use of partial cutting can be promoted through stumpage allowances, a market based system, packaging harvest units, and legislation.

Stumpage allowances will reduce the direct cost of fibre, however, a market based system will result in self regulating fibre costs that reflect market value and adjust for alternative silvicultural systems. While greater use of fibre into alternative products may result from a market based system, legislation may be needed to change log grades to better reflect the quality of timber or raise waste and residue penalties to promote improved utilization of poor quality fibre. The current BC stumpage system classifies timber as either a saw log or pulpwood grade (Ministry of Forests, 1995). This system is not suitable for over mature western red cedar from a utilization standpoint as contractors are not required to remove the pulpwood as no nearby processing facilities exist, even though alternative processing facilities for low grade fibre, such as post and rail, exist. If a greater percentage of fibre is recovered, the harvesting cost per cubic meter will decrease. While requiring licensees to partial cut a through legislation is an option, packaging favoured clearcut units with less preferred partial cut units is another option. Packaging the units at a flat cost, below that of traditional clearcuts would entice the licensees into partial cutting. Long term this would improve partial cutting practices and lower costs, as illustrated in the reduced planning and layout costs in the Minnow group selection treatment.

From a stand damage standpoint, steps can be taken to further reduce stand damage, however in over mature stands where the primary goal of retention is for stand structure not regeneration or the maintenance fibre quality, damage that does not result in mortality may be considered to be of limited consequence, providing the safety of humans in the stand is not impacted. Root damage has a significant effect on wind firmness and as such must also be considered in the context of human safety (Stathers et. al., 1994).

Social and environmental goals achieved by partial cutting, including visual quality, recreational opportunities, and wildlife habitat, must be considered and valued based on retention levels. From a tourism perspective, visual; quality and recreational opportunities are important in the Robson Valley (Moon et al., 2004). The area is marketed as a hub for an infinite variety of outdoor recreation opportunities with a range of micro-climates from rainforest to high alpine, where flora and fauna, large and small are abundant (http://mcbride.ca/).

Sheppard et al. (2004) found that visual quality objectives could easily be achieved through partial cutting. According to a public preference survey, retention treatments have a 70% preference over maximum modification treatments, while partial retention treatments have a 65% preference over maximum modification treatments (BC Ministry of Forests, 1997). According to the criteria (BC Ministry of Forests, 1997), retention, partial retention, and maximum modification treatments are equivalent to the group selection, group retention and clearcut treatments, respectively, in this study.

The retention of stand structure and islands of habitat along with an increased edge effect will maintain traditional old growth attributes required by species, such as woodland caribou, while promoting habitat for other species of flora and fauna. The Northern Rockies ICH/Silvicultural Systems Project will continue to monitor the effects of various partial cutting regimes on short-term and long-term stand growth and development, loss and creation of stand structural biodiversity attributes (wildlife trees and course woody debris), windthrow, regeneration, and tree mortality(Jull et al., 2002). This long term monitoring will help to put a financial value on various level of partial cutting.

5.3.9 Suggestions for Future Harvesting Operations

Partial cutting less often used in the interior of BC and specifically cedar dominant stands due to the perceived additional costs over clearcutting. As partial cutting becomes more common place, planning, layout, and harvesting costs will continue to decrease as operator knowledge increases. Based on this study, the following general suggestions may improve both clearcut and partial cut harvest of interior cedar stands:

1. Mark only the outer edge of retention or selection patches.

2. Mark patches and boundaries with colour blind friendly colours, red and greens should be avoided.

3. Improved skid trail layout; straight and level with any corners located with harvest openings will reduce stand damage, eliminate the need for rub features and associated costs, while likely improve skidding cycle times and thus productivity.

4. Larger over mature cedar can be mechanically felled by multiple cuts; however this practice is not suitable for large solid trees due to stump pull.

5. Match cuts when using multiple cuts to fell a tree, it will decrease volume loss during processing.

6. Felling tree into patches, skid trails, or openings will reduce residual stand damage especially when used in combination with top skidding.

7. Yarding corridor change time can be greatly decreased through pre planning.

8. A balanced harvest operation will result in decreased loading and processing costs

9. Pre work meetings can decrease operational delays

10. Merchantable volume per tree can have an affect on harvesting costs (Ashe, 1916; Lynford, 1934; Mann and Mifflin, 1979; Kluender et al., 1997). As such the merchantable volume per tree can be increased by exploring all possible products for species being harvested.

11. Stand damage could be decreased through the use of rub structures, (Bennett, 1993; Matzka, 1998; Kosicki, 2000a), incentive or bonus penalty program (McNeel and Dodd, 1996; Langeson, 1997), and/or operator education (Matzka, 1998).

12. Root damage can be avoided in partial cuts by not utilizing bladed skid trails.

5.3.10 Opportunities for Future Research

This study is part of the Northern Rockies ICH/Silvicultural Systems Project, established to examine ways of managing ICH and ESSF forests in a manner that would address both ecological and socio-economic concerns. While this study has provided information on the harvesting cost, productivity and stand damage for the particular treatments examined, it is not clear if these results can be replicated in other cedar dominated stands or if these results can be applied to other forest types, however general findings may be applicable. In addition, other harvesting treatments such as cable partial cuts and a conventionally harvested group retention treatment were not replicated. Further study in regards to patch and skid trail layout relation to residual stand damage is also recommended.

6 Conclusion

This study examined three silvicultural systems utilizing three harvesting systems in over mature interior cedar hemlock stands in east central British Columbia. Layout costs, harvesting productivity and costs, and residual stand damage were determined for each treatment. As expected the planning and layout costs were the lowest in the clearcut treatments ($\$0.45/m^3$-$0.68/m^3$) and followed by the group retention ($\$1.16/m^3$) and selection treatments ($\$1.73/m^3$-$\$2.62/m^3$). Harvesting costs varied in the conventional system treatments from $\$10.95/m^3$ - $\$16.09/m^3$ and from $\$13.45/m^3$-$\$17.37/m^3$ in the semi-mechanized system treatments. The cable system had a cost of $\$15.70/m^3$. It was expected that the harvesting costs would be lowest in the ground-based clearcut treatments followed by the group retention treatments, group selection and cable clearcut. It was also expected that the semi-mechanized system would be more cost effective than the conventional system. It was found that the semi-mechanized group retention treatment was the most cost effective. The semi-mechanized group selection was cheaper than the conventional group selection treatment due to a higher production rate common with mechanized harvesting operations. The cable clearcut was the most expensive treatment.

An understanding of the traditional and alternative products that can be derived from the harvested timber was key in increasing the amount of merchantable volume and reducing the corresponding harvesting costs. As such it is recommended that all possible product options be explored prior to processing to ensure the merchantable volume is maximized.

Stand damage was greatest in the group selection treatments; however mechanized felling showed a significant stand damage increase over manual felling as a result of felling practices. This was not expected as mechanized felling according to the literature results in greater control of the felled stem. Had the tree been felled toward the inside of harvest openings or skid trails this damage would have been greatly reduced. As expected, grapple skidding resulted in a lower level of stand damage than that of line skidding, this however may have been the result of poor skid trail layout and design in the line skidder treatment.

Partial cutting of cedar dominated stands needs to proceed with an increased emphasis on layout, alternative silvicultural trials, alternative commercial products, and the reduction of stand damage. This will ensure the continuation of commercial forestry while promoting ecological and socio-economic concerns.

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8 Glossary of Harvesting Terms

Butt'n top loader

A hydraulic loader that utilizes a special grapple to grasp logs in the middle. Out rigger arms on the grapple balance the logs. The grapple is able to turn the logs end for end. This facilitates truck loading by equalizing the payload. The grapple is designed to handle smaller logs.

Backspar

A tree or machine rigged at the back end of the work area to provide lift for yarding lines. It is also known as a tail spar.

Choker

A wire rope noose for hooking the logs to a yarder carriage or skidder.

Conventional harvesting system

Conventional system is a ground-based system that utilizes manual felling, line skidding, manual processing at the landing and mechanical loading

Heel-boom loader

A hydraulic loader that grasps logs at the end and using a movable heel, on the grapple, controls and tilts logs. The grapple is not able to turn logs end for end. and is designed to handle larger logs.

Hoe Chucking

The movement of felled timber with an excavator, using its bucket and thumb, and placing the timber into bunches.

Hook tender

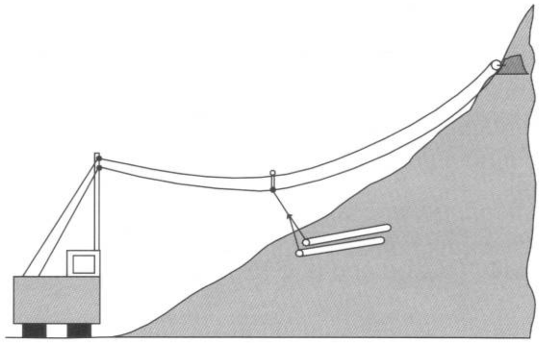
A hook tender is a person on the hill in cable yarding which uses chokers to attach trees to the carriage

Semi-mechanized harvesting system

Semi mechanized system is a ground-based system that utilizes mechanical and manual felling, grapple skidding, manual processing at the landing and mechanical loading

Running skyline

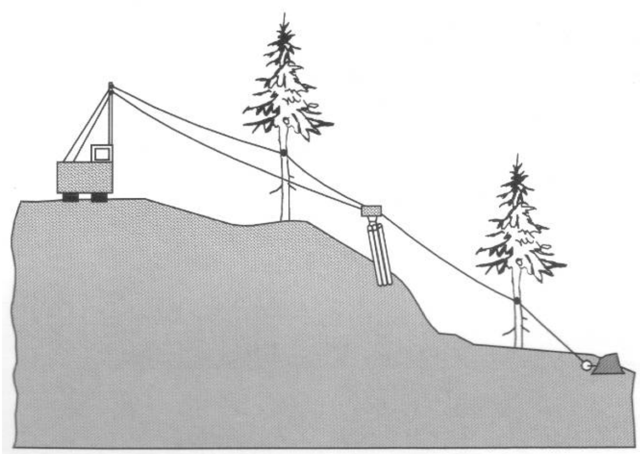
A running skyline system is similar to a skyline system except that the skyline (also known as a haulback line) cable is attached to the far end of the carriage and is used to return the carriage uphill. The mainline cable is attached to yarder end of the carriage while the haulback or skyline is attached to the opposite end. From the carriage, the skyline is passed though a pulley on the tail end of the system and returns to the yarder. The carriage is hung off of blocks on the haulback line. The weight of carriage and logs are distributed to both the skyline and mainline cables.



Running skyline system, figure from Macdonald, 1999

Skyline (multispan or single)

A skyline system uses a carriage running on a cable (skyline) that is used to partially or completely lift the logs. The skyline cable supports all the weight load weight while the load is pulled to the landing by the mainline. Unlike a running skyline system the skyline does not move. The figure below is a multispan skyline system (Macdonald, 1999). A multispan system uses intermediate supports to increase the deflection of the skyline cable, while a single span system has no intermediate supports.



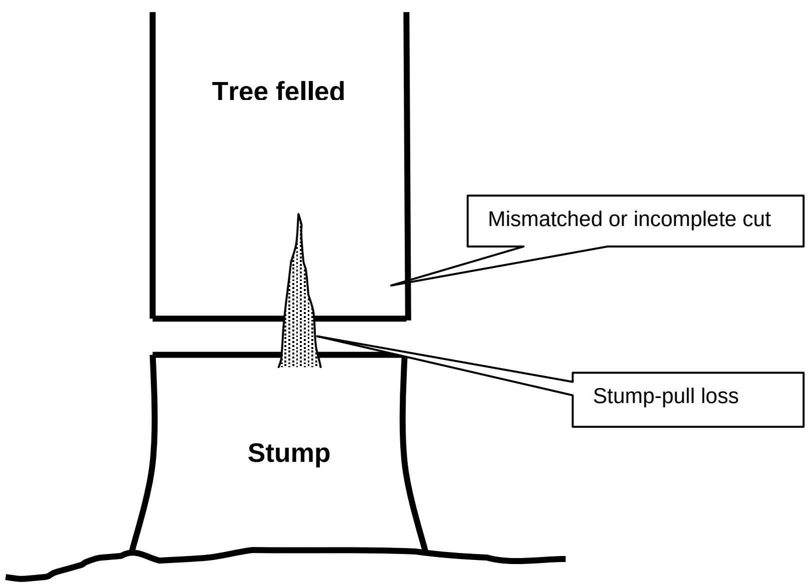
Multispan skyline system, figure from Macdonald, 1999

Slack pulling carriage

A slack-pulling carriage allows a yarding line to be pulled to the side of the skyline corridor., increasing the capability for lateral yarding. There are a variety of slack-pulling carriages ranging from line pulled totally by hand to carriages with an internal motor that feeds out the line.

Stump pull

Stump pull occurs when hinge wood is left in the middle of the stump and pulls fibre fro the centre of the felled tree during the felling process



Stump pull, figure adapted from Han and Renzie, 2005

Appendix 1 – East Twin Harvesting Equipment

Manual felling

John Deere 640 D Line Skidder – Ground-based Units

Madill J7C Tower Yarder – Cable Unit

Homemade Running Skyline Carriage

Manual Processing

John Deere 644E Front-end Log Loader – Ground-based Units

Barko 425 Heel-boom Log Loader – Cable Unit

Appendix 2 – Minnow Creek Harvesting Equipment

Timberjack 618 Feller Buncher

Manual Felling

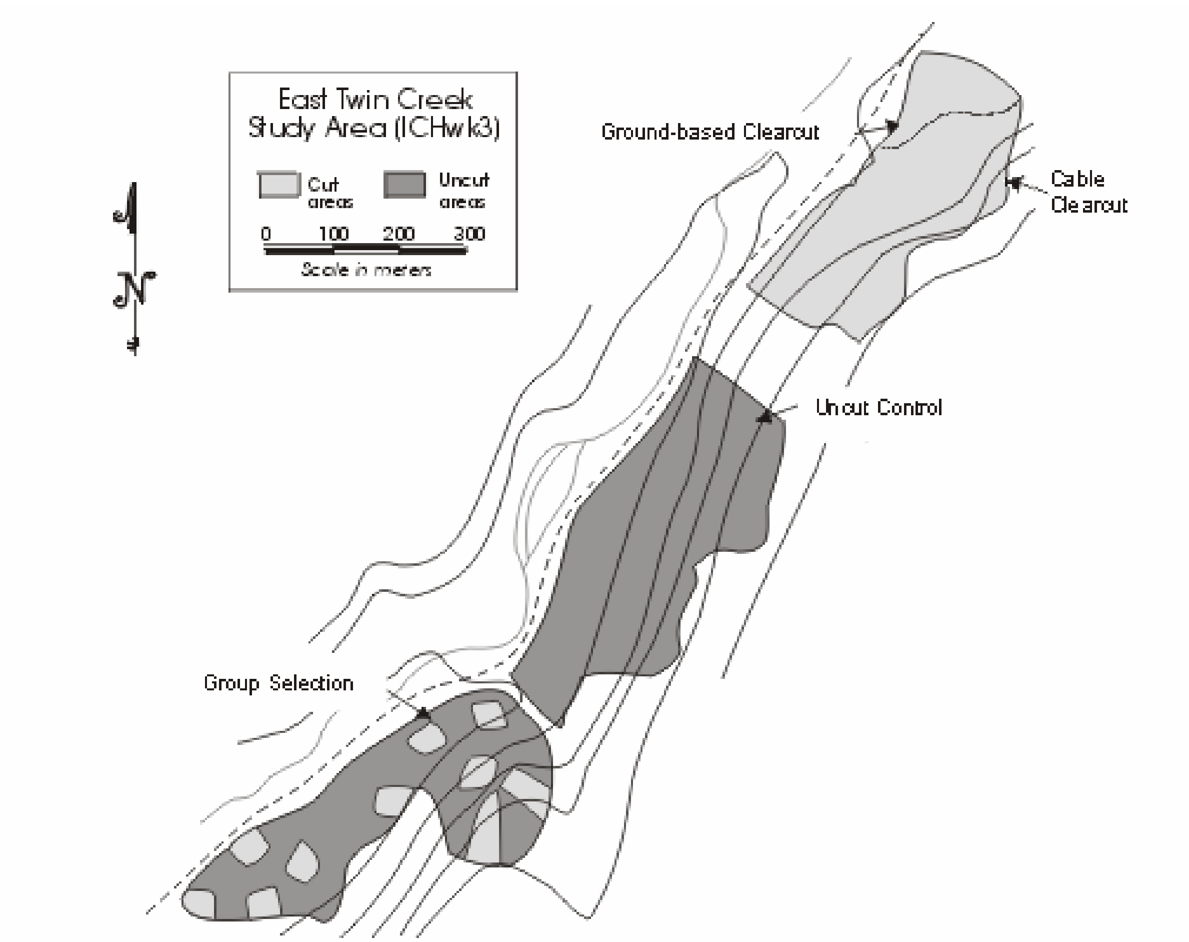
John Deere 748E Grapple Skidder

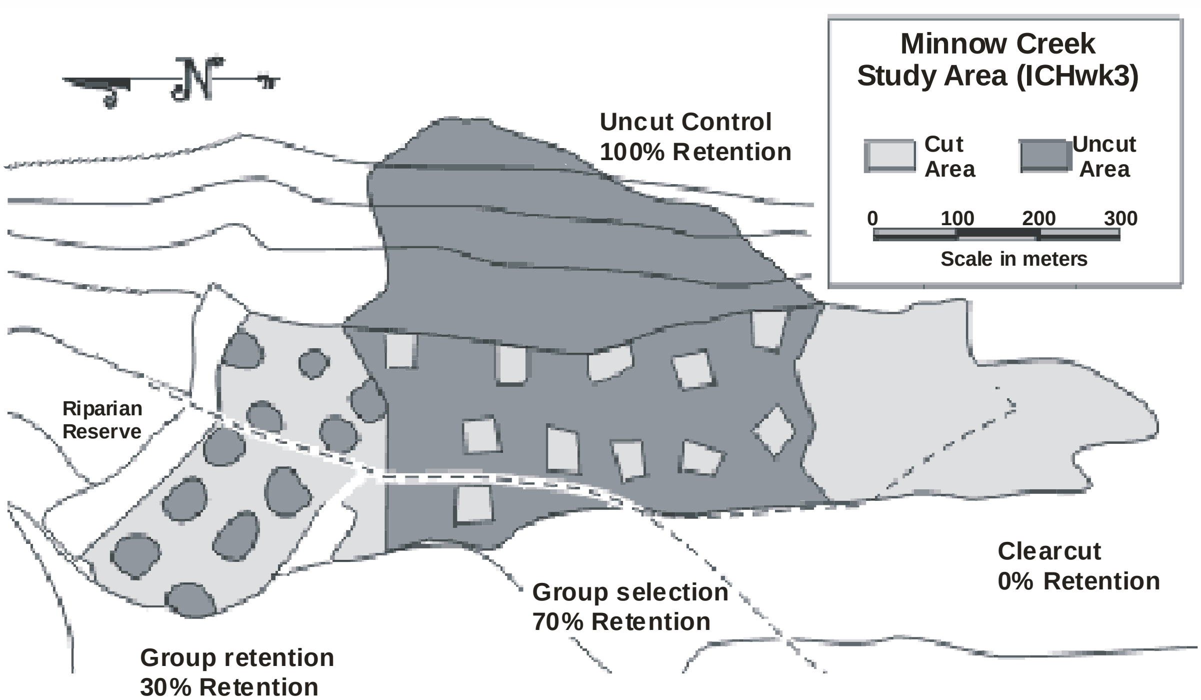
Hitachi EX270LC Excavator

Manual Processing

Komatsu WA 320 Front-end Log Loader

Appendix 3 – East Twin and Minnow Site Maps





Appendix 4 – Shift Level Forms

Manual Felling, Daily Shift Level Form
UNBC Forestry

Partial Cut Cost Analysis Study

Daily Felling Production

GENERAL INFORMATION

Date ____________________

Start Time:______________

Block: East Twin Cable Clearcut,
East Twin Ground Based Clearcut, or
East Twin 30% Removal

End Time:_______________

Break Time:_____________

Weather: Sunny Cloudy Snowing Rain

Temperature: _____________

FELLER PRODUCTION

	NAME	HOURS WORKED	TREES CUT
FELLER #1			
FELLER #2			

MECHANICAL DELAYS (GREATER THAN 10 MINUTES)

MINUTES	FELLER #	DESCRIPTION OF DELAY

OTHER DELAYS (GREATER THAN 10 MINUTES)

MINUTES	FELLER #	DESCRIPTION OF DELAY

COMMENTS (provide any additional information that helps to explain the day's production)

*** Please start a new form when moving to a different block**

Skidder, Daily Shift Level Form
UNBC Forestry

Partial Cut Cost Analysis Study

Daily Skidding Production

GENERAL INFORMATION

Date ____________________

Operator:______________

Block: East Twin Ground Based Clearcut, or
East Twin 30% Removal

Start Time:______________

End Time:______________

Weather: Sunny Cloudy Snowing Rain

Break Time:_____________

Temperature: ____________

SKIDDER PRODUCTION

Total # Turns__________ Total # Logs__________ Total # Tops__________

DELAYS (GREATER THAN 10 MINUTES)

MINUTES	**TYPE**	**DESCRIPTION OF DELAY**
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	

COMMENTS (provide any additional information that helps to explain the day's production)

Delay Types:
Mechanical – Any delay related to the mechanical failure of the skidder
Maintenance – Any time spent on regular maintenance of skidder during the shift
Personal – Operator related delay time
Other – Specify nature of delay in description of delay

*** Please start a new form when moving to a different block**

Yarder, Daily Shift Level Form
UNBC Forestry

Partial Cut Cost Analysis Study

Daily Yarding Production

GENERAL INFORMATION

Date ____________________

Operator:_______________

Block: East Twin Cable Clearcut

Start Time:______________

End Time:_______________

Weather: Sunny Cloudy Snowing Rain

Break Time:_____________

Temperature: _____________

YARDER PRODUCTION

Total # Turns___________ Total # Logs___________ Total # Tops__________

DELAYS (GREATER THAN 10 MINUTES)

MINUTES	TYPE	DESCRIPTION OF DELAY
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	

COMMENTS (provide any additional information that helps to explain the day's production)

Delay Types:
Mechanical – Any delay related to the mechanical failure of the yarder
Maintenance – Any time spent on regular maintenance of yarder during the shift
Personal – Operator related delay time
Other – Specify nature of delay in description of delay

*** Please start a new form when moving to a different block**

Daily Bucking Production

GENERAL INFORMATION

Date ____________________

Start Time:______________

Block: East Twin Cable Clearcut,
East Twin Ground Based Clearcut, or
East Twin 30% Removal

End Time:_______________

Break Time:_____________

Weather: Sunny Cloudy Snowing Rain

Temperature: _____________

BUCKER PRODUCTION

	NAME	HOURS WORKED	TREES CUT
BUCKER #1			
BUCKER #2			

MECHANICAL DELAYS (GREATER THAN 10 MINUTES)

MINUTES	BUCKER #	DESCRIPTION OF DELAY

OTHER DELAYS (GREATER THAN 10 MINUTES)

MINUTES	BUCKER #	DESCRIPTION OF DELAY

COMMENTS (provide any additional information that helps to explain the day's production)

*** Please start a new form when moving to a different block**

Daily Loader Production

GENERAL INFORMATION

Date ____________________ Operator:_______________

Block: East Twin Cable Clearcut,
East Twin Ground Based Clearcut, or
East Twin 30% Removal

Start Time:_______________

End Time:_______________

Weather: Sunny Cloudy Snowing Rain

Break Time:_____________

Temperature: _____________

LOADER PRODUCTION

Truck #	Total # of Logs	Destination of Load	Truck #	Total # of Logs	Destination of Load

DELAYS (GREATER THAN 10 MINUTES)

MINUTES	TYPE	DESCRIPTION OF DELAY
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	

COMMENTS (provide any additional information that helps to explain the day's production)

Delay Types:
Mechanical – Any delay related to the mechanical failure of the skidder
Maintenance – Any time spent on regular maintenance of skidder during the shift
Personal – Operator related delay time
Other – Specify nature of delay in description of delay

*** Please start a new form when moving to a different block**

Manual Felling, Daily Shift Level Form
UNBC Forestry

Partial Cut Cost Analysis Study

Daily Felling Production

GENERAL INFORMATION

Date ____________________

Start Time:______________

Block: Minnow Clearcut,
Minnow 70% Removal, or
Minnow 30% Removal

End Time:________________

Break Time:_____________

Weather: Sunny Cloudy Snowing Rain

Temperature: _____________

FELLER PRODUCTION

	NAME	HOURS WORKED	TREES CUT
FELLER #1			
FELLER #2			

MECHANICAL DELAYS (GREATER THAN 10 MINUTES)

MINUTES	FELLER #	DESCRIPTION OF DELAY

OTHER DELAYS (GREATER THAN 10 MINUTES)

MINUTES	FELLER #	DESCRIPTION OF DELAY

COMMENTS (provide any additional information that helps to explain the day's production)

*** Please start a new form when moving to a different block**

Skidder, Daily Shift Level Form
UNBC Forestry

Partial Cut Cost Analysis Study

Daily Skidding Production

GENERAL INFORMATION

Date ____________________

Operator:_______________

Block: Minnow Clearcut,
Minnow 70% Removal, or
Minnow 30% Removal

Start Time:_______________

End Time:_______________

Weather: Sunny Cloudy Snowing Rain

Break Time:_____________

Temperature: _____________

SKIDDER PRODUCTION

Total # Turns___________ Total # Logs___________ Total # Tops__________

DELAYS (GREATER THAN 10 MINUTES)

MINUTES	TYPE	DESCRIPTION OF DELAY
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	

COMMENTS (provide any additional information that helps to explain the day's production)

Delay Types:
Mechanical – Any delay related to the mechanical failure of the skidder
Maintenance – Any time spent on regular maintenance of skidder during the shift
Personal – Operator related delay time
Other – Specify nature of delay in description of delay

*** Please start a new form when moving to a different block**

Daily Bucking Production

GENERAL INFORMATION

Date ____________________

Start Time:______________

Block: Minnow Clearcut,
Minnow 70% Removal, or
Minnow 30% Removal

End Time:_______________

Break Time:______________

Weather: Sunny Cloudy Snowing Rain

Temperature: _____________

BUCKER PRODUCTION

	NAME	HOURS WORKED	TREES CUT
BUCKER #1			
BUCKER #2			

MECHANICAL DELAYS (GREATER THAN 10 MINUTES)

MINUTES	BUCKER #	DESCRIPTION OF DELAY

OTHER DELAYS (GREATER THAN 10 MINUTES)

MINUTES	BUCKER #	DESCRIPTION OF DELAY

COMMENTS (provide any additional information that helps to explain the day's production)

*** Please start a new form when moving to a different block**

Daily Loader Production

GENERAL INFORMATION

Date ____________________ Operator:_______________

Block: Minnow Clearcut,
Minnow 70% Removal, or
Minnow 30% Removal

Start Time:_______________

End Time:_______________

Weather: Sunny Cloudy Snowing Rain

Break Time:_____________

Temperature: _____________

LOADER PRODUCTION

Truck #	Total # of Logs	Destination of Load	Truck #	Total # of Logs	Destination of Load

DELAYS (GREATER THAN 10 MINUTES)

MINUTES	TYPE	DESCRIPTION OF DELAY
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	
	Maintenance Mechanical Personal Other	

COMMENTS (provide any additional information that helps to explain the day's production)

Delay Types:
Mechanical – Any delay related to the mechanical failure of the skidder
Maintenance – Any time spent on regular maintenance of skidder during the shift
Personal – Operator related delay time
Other – Specify nature of delay in description of delay

*** Please start a new form when moving to a different block**

Appendix 5 – Detailed Time Elements

Dependent and independent variables for timing manual felling

Manual felling			
Dependent Variables		Independent Variables	
Name	*Definition*	*Name*	*Definition*
Cycle elements:			
Cut	process of cutting tree	Diameter	stump diameter (cm), taken when possible
Move	process of moving to next tree	Treatment area	silvicultural treatment: clearcut, group selection and group retention
Brush	clearing brush around tree	Tree number	sample number
Wedge	using a wedge to direct tree during felling	Road method	designated and non-designated
Shovel	removal of snow from around stem	Slope	slope of ground (%)
Reconnaissance	examination of terrain to determine which tree to fell next	Species	tree species: western red cedar, subalpine fir, Engelmann spruce, western hemlock
Delays:			
Fuel	fuelling of saw		
File	sharpening of saw		
Fix saw	repairing of saw		
Rest	short break		
Walk in or out	travel in or out of work area		
Move equipment	moving of spare saw or tools		
Meetings	safety or production meeting		
Other delays	unexpected delays - mechanical, operational, and personal. details noted		

Dependent and independent variables for timing a feller buncher

Feller buncher			
Dependent Variables		Independent Variables	
Name	*Definition*	*Name*	*Definition*
Cycle elements:			
Cut	process of cutting tree	Treatment area	silvicultural treatment: clearcut, group selection and group retention
Move	process of moving to next tree	Tree number	sample number
Brush	clearing brush around tree	Road method	designated and non-designated
Push	pushing over of tree by feller buncher	Slope	slope of ground (%)
Bunch	grouping of felled stems	Species	tree species: western red cedar, subalpine fir, Engelmann spruce, western hemlock
Reconnaissance	examination of terrain to determine which tree to fell next		
Delays:			
Fuel	fuelling of feller buncher		
Walk in or out	Travel in or out of work area		
Rest	short break		
Meetings	safety or production meeting		
Other Delays	unexpected delays - mechanical, operational, and personal. details noted		

Dependent and independent variables for timing a skidder equipped with a winch line

Skidder equipped with a winch line			
Dependent Variables		Independent Variables	
Name	*Definition*	*Name*	*Definition*
Cycle elements:			
Travel empty	travel out to get a turn of logs	Treatment area	silvicultural treatment: clearcut, group selection and group retention
Positioning	process of moving to next log or bunch of logs	Turn number	sample number
Line out	mainline released from skidder to facilitate log choking	Travel distance	distance traveled (m)
Choking	process of choking logs	Road method	designated and non-designated
Line in	Winding up of mainline to skidder to facilitate travel	Slope	slope of ground or trail (%)
Travel loaded	travel back to landing with a load of logs	Chokers	number of chokers used per turn
Delimbing	removal of tree limbs	Logs	number of trees/logs per turn
Clear trail	clearing trail to facilitate travel	Trees choked	number of trees choked per turn
Unhook turn	unhooking chokers		
Reconnaissance	examination of terrain to determine which log or group of logs to skid next		
Delays:			
Fuel	fuelling of skidder		
Walk in or out	Travel in or out of work area		
Rest	short break		
Meetings	safety or production meeting		
Other Delays	unexpected delays - mechanical, operational, and personal. details noted		

Dependent and independent variables for timing a grapple skidder

Grapple skidder			
Dependent Variables		Independent Variables	
Name	*Definition*	*Name*	*Definition*
Cycle elements:			
Travel empty	travel out to get a turn of trees	Treatment area	silvicultural treatment: clearcut, group selection and group retention
Positioning	process of moving to next log or bunch	Turn number	sample number
Accumulate	grouping of logs into a bunch	Travel distance	distance traveled (m)
Load	process of closing and lifting grapple	Road method	designated and non-designated
Travel loaded	travel back to landing with a load of logs	Slope	slope of ground or trail (%)
Unloading	opening grapple to release logs	Logs	number of trees/logs per turn
Separate	Separating logs after unloading to facilitate delimbing and manual processing		
Delimbing	removal of tree limbs		
Reconnaissance	examination of terrain to determine which tree to fell next		
Delays:			
Fuel	fuelling of skidder		
Clear trail	clearing trail to facilitate travel		
Walk in or out	Travel in or out of work area		
Rest	short break		
Meetings	safety or production meeting		
Other Delays	unexpected delays - mechanical, operational, and personal. details noted		

Dependent and independent variables for timing a running skyline system

Yarder with a running skyline system			
Dependent Variables		Independent Variables	
Name	*Definition*	*Name*	*Definition*
Cycle elements:			
Outhaul	carriage travels out to get a turn of trees	Turn number	sample number
Hooking	process of choking logs	Yarding distance	distance yarded (m)
Inhaul	carriage travels back to landing with a turn of logs	Slope	slope of ground or trail (%)
Unhooking	process of removing chokers from logs	Chokers	number of chokers used per turn
Delimbing	removal of tree limbs	Logs	number of trees/logs per turn
Delays:			
Setting change	changing yarding corridor		
Wait for choker	delay caused by hook tender on hill		
Wait for loader	delay caused by loader on landing		
Wait for chaser	delay caused by chaser on landing		
Wait for skidder	delay caused by skidder		
Fuel	fuelling of yarder		
Walk in or out	Travel in or out of work area by hook tenders		
Meetings	safety or production meeting		
Other Delays	unexpected delays - mechanical, operational, and personal. details noted		

Appendix 6 – East Twin Machine Costs

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 7 – Minnow Machine Costs

	Timber Jack 618 Feller Buncher	John Deere 748E Grapple Skidder	Komatsu WA320 Front-end Log Loader	Hitachi EX270LC Excavator	Caterpillar D7H Tractor
OWNERSHIP COSTS					
Total Purchase Price (P) $	465,000	330,000.00	239,000.00	355,000.00	575,000.00
Expected Life (Y) y	5	5	5	5	5
Expected Life (H) h	10000	10000	10000	10000	10000
Scheduled hours/year (h)=(H/Y) h	2000	2000	2000	2000	2000
Salvage value as % of P (s) %	20.00	25.00	30.00	30.00	30.00
Interest rate (Int) %	10	10	10	10	10
Insurance rate (Ins) %	3	3	3	3	3
Salvage value (S)=(P*s)/100) $	93,000.00	82,500.00	71,700.00	106,500.00	172,500.00
Average investment	186,000.00	206,250.00	83,650.00	124,250.00	201,250.00
Loss in resale value ((P-S)/H) $/h	37.20	24.75	16.73	24.85	40.25
Interest ((Int*AVI)/h) $/h	9.30	10.31	4.18	6.21	10.06
Insurance ((Ins*AVI)/h) $/h	2.79	3.09	1.25	1.86	3.02
Total ownership costs (OW) $/h	49.29	38.16	22.17	32.93	53.33
OPERATING COSTS					
Fuel Consumption Diesel (F) L/h	30.00	25.00	35	32	23
Fuel Cost Diesel (fc) $/L	0.50	0.50	0.50	0.50	0.50
Lube and oil as % of fuel (fp) %	20	15	15	15	15
Track and undercarriage	30,000.00	0.00	0	8000	20000
Track and undercarriage life (Th) h	5,000.00	0.00	0	10000	10000
Annual repair & maintenance (Rp) $	86,400.00	49,600.00	22000	32000	14000
Annual operating supplies (Oc) $	0.00	0.00	0	0	1500
Annual tire consumption (t) no.	0.00	2.00	2	0	
Tire replacement (tc) $	0.00	3,300.00	2300	0	
Operator wages $/h	25.00	25.00	25	25	25
Wage benefit loading (WBL) %	35	35	35	35	35
Shift length (sl) h	8	8	8	8	8
Fuel (F*fc) $/h	15.00	12.50	17.50	16.00	11.50
Lube and oil ((fp/100*(F*fc)) $/h	6.00	3.75	5.25	4.80	3.45
Tires ((tc*t)/h) $/h	0.00	3.30	2.30	0.00	
Repair and maintenance (Rp/h) $/h	43.20	24.80	11.00	16.00	7.00
Track and Undercarriage (Tc/Th)	6.00	0.00	0.00	0.00	2
Operating supplies (Oc/h) $/h	0.00	0.00	0.00	0.00	0.75
Wages and benefits (W*(1+WBL/100) $/h	33.75	33.75	33.75	33.75	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	103.95	78.10	69.8	70.55	58.45
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	153.24	116.26	91.97	103.48	111.78

[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 8 –Time data for East Twin Felling

	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	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

Treatment	Group Selection (70% retention)	Clearcut Ground-based	Clearcut Cable
Feller	A	A	B
Volume / PMH (m^3/hr)	39.27	46.60	68.37
Volume / SMH (m^3/hr)	23.37	25.81	44.76
Felling cost ($/hr)	50.00	50.00	50.00
Felling cost / PMH ($/$m^3$)	1.27	1.07	0.73
Felling cost / SMH ($/$m^3$)	2.14	1.94	1.12

Appendix 9 – Time Data for East Twin Skidding

	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	0.12	0.55	0.07	0.29
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
Reconnaissance	0.03	0.14	0.02	0.11
Turning on landing	1.53	7.16	0.00	0.00
Total Productive Time	18.47	86.55	15.50	83.74
Wait for tractor skidder	0.31	1.46	0.20	1.09
Wait for faller	0.14	0.65	0.00	0.00
Repair winch line	0.33	1.32	0.50	2.70
Wait for loader	0.15	0.68	0.13	0.71
Personal delay	0.05	0.24	0.14	0.73
General repair	0.04	0.19	0.00	0.00
Choker repair	0.63	2.97	0.00	0.00
Rechoking tree(s)	0.14	0.67	0.00	0.00
Clearing skid trail	0.22	1.03	0.41	2.24
Total Non-Productive Time	2.87	13.45	3.01	16.26
Total Cycle Time	21.34	100.00	18.50	16.26

Treatment	Group Selection (70% retention)	Clearcut Ground-based
Average distance (m)	238.70	140.80
Number of chokers available	8	5
Choking averages		
Trees in choke #1/cycle (no.)	2.86	2.43
Trees in choke #2/cycle (no.)	1.72	1.11
Trees in choke #3/cycle (no.)	0.89	0.51
Trees in choke #4/cycle (no.)	0.32	0.30
Trees in choke #5/cycle (no.)	0.07	0.00
Average pieces/cycle (no.)	5.86	4.35
Volume / PMH (m^3/hr)	23.22	25.95
Volume / SMH (m^3/hr)	20.09	21.72
Skidder cost ($/hr)	89.74	89.74
Skidding cost / PMH ($/$m^3$)	3.86	3.50
Skidding cost / SMH ($/$m^3$)	4.47	4.13

Appendix 10 –Time Data for East Twin Yarding

	Avg. time /element (min)	Time/Cycle (%)		Avg. time /element (min)	Time/Cycle (%)
Productive Cycle Elements			**Non-productive Elements**		
Outhaul	0.740	7.80	Yarder setting change time	1.006	10.68
Hookup	3.130	33.22	Warm and fuel up	0.317	3.36
Hookup #2	0.130	1.35	Replacing choker	0.187	1.98
Inhaul	2.240	23.83	Repairing mainline	0.168	1.78
Unhook	0.840	8.89	General repairs	0.116	1.23
			Adjusting guylines	0.082	0.87
Total productive time	7.080	75.10	Wait for loader	0.081	0.86
			Repairing haulback drum	0.077	0.82
			Broken strawline	0.070	0.74
			Adjusting haulback brake	0.052	0.55
			Tangled lines	0.050	0.53
			Rechoking log	0.047	0.5
			Untangling logs	0.032	0.34
			Wait for chokerman	0.030	0.32
			Communication	0.024	0.26
			Repairing carriage	0.021	0.22
			Personal delay	0.020	0.21
			Crossed lines	0.005	0.05
			Wait for bucker	0.004	0.04
			Wait for chaser	0.001	0.01
Total cycle time (min)	9.420	100.00	Total non-productive time	2.388	24.90

Cycles per hour (no.)	6.37
Avg. pieces/cycle (no.)	2.59
Avg. 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/PMH(m^3/hr)	32.49
Volume/SMH	24.25
Yarder cost ($/hr)	187.58
Yarding cost/PMH ($/$m^3$)	5.77
Yarding cost/SMH ($/$m^3$)	7.74

Appendix 11 – Detailed East Twin Landing Activity Sampling

Harvesting system			Ground-based				Cable	
Silvicultural treatment			Group selection		Clearcut		Clearcut	
		Element [a]	Time (min/hr)	% of time	Time (min/hr)	% of time	Time (min/hr)	% of time
Skidder/yarder	Delay	Delayed on Landing	0.00	0.00	0.00	0.00	0.00	0.00
	Productive	Off 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
Loader	Delay	Delayed on landing	2.76	4.59	2.33	3.89	11.25	18.75
		Waiting for logs	29.39	48.98	30.33	50.56	3.00	5.00
	Productive	Working	27.86	46.43	27.33	45.56	45.75	76.25
Bucker	Delay	Delayed from working	3.37	5.61	3.00	5.00	7.13	11.88
		Waiting for logs	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
	Productive	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.

Appendix 12 –Time data for Minnow Mechanized Felling

	Avg. time / element (min)	Time / Cycle (%)	Avg. time / element (min)	Time / Cycle (%)	Avg. time / element (min)	Time / Cycle (%)
Silvicultural treatment	**Group selection**		**Group retention**		**Clearcut**	
Productive Elements:						
Moving from tree to tree	0.34	24.37	0.31	22.97	0.37	29.09
Brushing	0.12	8.43	0.10	7.48	0.07	5.70
Cutting	0.04	3.08	0.10	7.47	0.05	3.95
Pushing	0.01	0.90	0.02	1.28	0.03	2.03
Bunching	0.26	18.31	0.21	15.31	0.24	18.66
Repositioning	0.01	0.85	0.11	8.43	0.09	6.97
Reconnaissance	0.03	2.06	0.02	1.33	0.01	1.13
Total Productive Time	0.82	57.99	0.87	64.27	0.87	67.54
Non Productive Elements						
Walking	0.15	10.42	0.04	3.16	0.07	5.39
Resting	0.07	5.17	0.06	4.71	0.05	4.07
Personal	0.04	2.86	0.06	4.49	0.01	0.68
Wait for skidder	0.00	0.00	0.03	2.07	0.00	0.35
Communication	0.07	4.69	0.05	3.99	0.11	8.60
Clearing trail	0.00	0.14	0.00	0.00	0.00	0.04
Stuck	0.12	8.37	0.00	0.00	0.00	0.00
Repair	0.02	1.59	0.09	6.93	0.04	3.20
Lunch	0.06	4.17	0.06	4.19	0.05	4.16
Warming up	0.04	3.10	0.04	3.09	0.04	2.99
Fuelling up	0.04	3.10	0.04	3.09	0.04	2.99
Total Non-Productive Time	0.59	42.01	0.48	35.73	0.42	32.46
Total Cycle Time	1.41	100.00	1.35	100.00	1.29	100.00

Silvicultural treatment	**Group selection**	**Group retention**	**Clearcut**
Average slope (%)	21.04	12.17	28.49
Total trees multicut (%)	3.24	16.81	10.14
Volume / tree (m^3)	1.05	1.07	0.91
Volume / PMH (m^3/hr)	77.34	74.36	62.96
Volume / SMH (m^3/hr)	44.85	47.79	42.52
Felling cost ($/hr)	153.24	153.24	153.24
Felling cost / PMH ($/$m^3$)	1.98	2.06	2.43
Felling cost / SMH ($/$m^3$)	3.42	3.21	3.60

Appendix 13 – Time Data for Minnow Skidding

	Avg. time / element (min)	Time / Cycle (%)	Avg. time / element (min)	Time / Cycle (%)	Avg. time / element (min)	Time / Cycle (%)
Silvicultural treatment	**Group selection**		**Group retention**		**Clearcut**	
Productive Elements:						
Travel empty	3.18	24.20	2.30	25.59	4.64	32.10
Loading	0.19	1.43	0.34	3.74	0.21	1.48
Accumulating	0.98	7.49	0.70	7.77	1.14	7.88
Repositioning	0.00	0.00	0.00	0.04	0.00	0.01
Travel loaded	3.06	23.25	2.50	27.76	3.78	26.16
Unloading	0.05	0.36	0.10	1.11	0.04	0.30
Separating skidded trees	0.68	5.15	0.40	4.41	0.70	4.83
Delimbing	0.44	3.35	0.90	10.00	0.51	3.56
Reconnaissance	0.06	0.45	0.04	0.46	0.03	0.23
Total Productive Time	8.63	65.67	7.27	80.89	11.07	76.56
Non Productive Elements						
Clearing trail	0.00	0.00	0.15	1.68	0.63	4.36
Traveling between landings	0.04	0.30	0.01	0.16	0.16	1.11
Communications	0.47	3.61	0.08	0.91	0.45	3.08
Personal	0.10	0.76	0.01	0.14	0.05	0.35
Wait on landing	0.00	0.00	0.40	4.49	0.36	2.48
Wait for felling	0.00	0.00	0.01	0.14	0.01	0.09
Wait for hoe chucking	0.14	1.04	0.00	0.00	0.19	1.29
Wait for cat	0.00	0.00	0.04	0.44	0.00	0.00
Maintenance	0.19	1.45	0.05	0.56	0.20	1.35
Mechanical	1.56	11.85	0.00	0.00	0.11	0.75
Forwarding processed wood	0.36	2.77	0.06	0.61	0.23	1.58
Clearing landing	0.08	0.62	0.19	2.09	0.08	0.59
Skidder or turn stuck	0.00	0.00	0.00	0.00	0.05	0.32
Warming up	0.48	3.67	0.41	4.52	0.46	3.16
Fuelling up	0.42	3.18	0.30	3.35	0.42	2.92
Total Non-Productive Time	4.51	34.33	1.72	19.11	3.39	23.44
Total Cycle Time	13.14	100.00	8.99	100.00	14.47	100.00

Silvicultural treatment	Group selection	Group retention	Clearcut
Average pieces/cycle (no.)	4.83	4.60	5.63
Average slope (%)	15.49	13.35	27.18
Average turn length (m)	26.17	28.33	25.00
Average distance loaded (m)	246.75	133.89	273.70
Average distance empty (m)	246.75	133.89	289.16
Turns hoe chucked (%)	20.18	0	25.58
Volume / tree (m^3)	1.05	1.07	0.91
Volume / turn (m^3)	5.09	4.9376218	5.13
Volume / PMH (m^3/hr)	35.40	40.73	27.81
Volume / SMH (m^3/hr)	23.25	32.95	21.29
Skidder cost ($/hr)	116.26	116.26	116.26
Skidding cost / PMH ($/$m^3$)	3.28	2.85	4.18
Skidding cost / SMH ($/$m^3$)	5.00	3.53	5.46

Appendix 14 –Detailed Minnow 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**	
Skidder/yarder	Delay	Delayed on Landing	2.31	3.85	2.62	4.36	5.44	9.06
	Productive	Off landing	46.62	77.69	40.00	66.67	44.23	73.72
		Working	11.08	18.46	17.38	28.97	10.33	17.22
Loader	Delay	Delayed on landing	16.15	26.92	4.92	8.21	12.33	20.54
		Waiting for logs	2.00	3.33	7.69	12.82	3.08	5.14
	Productive	Working	41.85	69.74	47.38	78.97	44.59	74.32
Bucker	Delay	Delayed from working	12.77	21.28	5.54	9.23	4.89	8.16
		Waiting for logs	12.31	20.51	7.85	13.08	19.94	33.23
		Refuelling and/or filing [b]	2.77	4.62	6.15	10.26	3.81	6.34
	Productive	Working	32.15	53.59	40.46	67.44	31.36	52.27

[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.