Advantage

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Contents

Helicopter logging with the Bell 214B: retention and clearcut harvesting in the southern interior of British Columbia

Abstract

The Forest Engineering Research Institute of Canada (FERIC) studied a light-lift helicopter operation near Lillooet, B.C. A Bell 214B was used to harvest variable retention and clearcut units on steep slopes. This report presents productivity and cost information on the helicopter logging operation, and discusses factors affecting the efficiency of the operation.

Keywords

Helicopter logging, Bell 214B, Partial cutting, Retention, Clearcut, Productivity, Costs, British Columbia.

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Executive summary

FERIC has established an ongoing study of helicopter logging operations throughout British Columbia to provide information on the capabilities and performances of different helicopters in typical harvesting situations. In this study, a Bell 214B was used to harvest a combination of variable retention and clearcut units on steep mountain slopes near Lillooet, B.C. Helicopter yarding had been prescribed for the area to address steep terrain, visual quality objectives, and the need to maintain wildlife and cultural heritage resources.

The helicopter operation harvested 32 026 m^3. The falling phase averaged 91.2 m^3/shift in 351 faller shifts, the helicopter yarding phase averaged 260 m^3/shift in 123 shifts, and the loading phase averaged 133 m^3/shift in 240 loader shifts.

The estimated cost of the operation was \$80.17/m^3. The falling cost, including helipad construction, was \$4.50/m^3 (6% of the total cost); the helicopter yarding cost was \$64.48/m^3 (80%); and the loading cost was \$11.19/m^3 (14%). The cost of the Bell 214B helicopter was estimated at \$44.31/m^3, or 69% of the yarding cost and 55% of the total cost.

Falling productivity was primarily affected by steep and difficult falling ground, the degree of in-woods manufacturing performed, and long hikes to and from worksites. The harvesting prescriptions themselves appeared to have had little effect on falling productivity.

Yarding productivity for this project was below the cooperators' expectations. Several factors influenced the helicopter's productivity in this study: high cull factor, landing size and design, retention harvesting prescriptions, poor weather conditions, long flight distances, use of only one loader on one of the sites, and lack of dust control.

This report examines several alternative helicopter logging scenarios: increasing in-woods manufacturing, changing the harvesting schedule, changing rigging equipment, maintaining consistent yarding cycle lengths, and overnighting the helicopter at the service landings rather than at the local airport. The analysis indicated that increasing in-woods manufacturing would have likely produced the highest overall cost savings, and highlighted the importance of exploring alternative harvesting options prior to committing to a harvesting approach.

The study reflected some of the operational challenges associated with harvesting clearcut and retention prescriptions with a light-lift helicopter in the interior of British Columbia. It illustrated the importance of several factors that affect overall system performance and cost, including adequate in-woods log manufacturing, appropriate landing size and design, weather, project size, and equipment complement.

Introduction

Forest engineers and planners recognize that helicopter logging is a highly specialized system with its own unique requirements for safe, cost-effective harvesting operations. However, information about the capabilities and performances of different helicopters in typical harvesting situations in British Columbia is scarce, as is information about site, stand, organizational, and operational factors that influence helicopter logging productivity and cost. FERIC has established an ongoing project to study helicopter logging operations throughout British Columbia to provide this information.

This report presents the results of a case study of a light-lift helicopter logging operation on five sites in the southern interior where steep slopes and visual quality objectives limited road construction and conventional cable yarding. A Bell 214B helicopter was used to harvest a combination of variable retention and clearcut units. FERIC, Ainsworth Lumber Co. Ltd., Transwest Timber Incorporated, Grand Island Logging Limited, and Denny's Tree Falling Services cooperated in this study.

Objectives

The goal of FERIC's project is to provide forest engineers with information on the capabilities, productivities, and costs of helicopters currently used for logging in British Columbia through an ongoing series of short-term case studies. The objectives of this case study were to:

- Describe the harvesting operation, and determine overall productivities and costs for the falling, helicopter yarding, and loading phases.
- Compare harvesting productivities for the harvesting treatments.
- Identify features of the site, stand, harvest plan, and system organization that may have influenced harvesting productivity and cost.

Site and stand description

The study was carried out on Crown land in the Cayoosh Creek watershed southwest of Lillooet, B.C., in the Southern Interior Forest Region. The study included five sites representing the Interior Douglas-fir (IDFdk, IDFxh), Montane Spruce (MSdc), and Engelmann Spruce-Subalpine fir (ESSFdv) biogeoclimatic zones (Lloyd et al. 1990). Forest cover consisted primarily of Douglas-fir *(Pseudotsuga menziesii)* except for Site 5 where Engelmann spruce *(Picea engelmannii)* was the primary species. Secondary components of the stands consisted of Engelmann spruce or Douglas-fir (depending on the site), lodgepole pine *(Pinus contorta)*, western red cedar *(Thuja plicata)*, amabilis fir *(Abies amabilis)*, and western white pine *(Pinus monticola)* (Table 1).

Net merchantable volumes on the sites ranged from 191 to 483 m^3/ha. Terrain was steep and broken on all sites with average slopes ranging from 35 to 80%. Soils were mostly colluvial with high coarse fragment contents and ongoing colluvial activity, except for Site 4 which had well-drained shallow soils over bedrock. Landslide risk following harvest was considered low for all sites.

Harvesting prescription and plan

The study area was cruised and engineered by Ainsworth. The five sites consisted of eleven cutblocks containing an estimated net volume of 31 000 m^3. Harvesting with a light-lift helicopter was prescribed to address

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Table 1. Site and stand description

	Gross cutblock area (ha)	Ecological classification [a]	Average slope (%)	Species composition: Douglas-fir (%)	Engelmann spruce (%)	Lodgepole pine (%)	Other (%)	Defect [b] (%)	Net [b] volume (m^3/ha)
Site 1									
Cutblock 1	10.5	IDFdk	70	75	14	6	5	12	337
Site 2									
Cutblock 1	8.1	IDFdk1	55	75	14	6	5	12	337
Site 3									
Cutblock 1	7.9	MSdc	80	44	10	26	20	16	415
Cutblock 2	10.6	MSdc	70	62	12	9	17	16	415
Site 4									
Cutblock 1	14.1	IDFxh	60	90	5	5	-	12	191
Cutblock 2	11.4	MSdc, IDFdk	57	65	11	9	15	16	415
Cutblock 3	15.9	IDFdk	60	85	7	1	7	10	223
Site 5									
Cutblock 1	2.1	ESSFdv	35	0	71	13	16	12	450
Cutblock 2	4.8	ESSFdv	45	0	71	13	16	12	450
Cutblock 3	5.5	ESSFdv	65	31	58	2	9	8	483
Cutblock 4	2.6	MSdc	65	31	58	2	9	8	483

[a] Lloyd et al. 1990.
[b] From timber cruise.

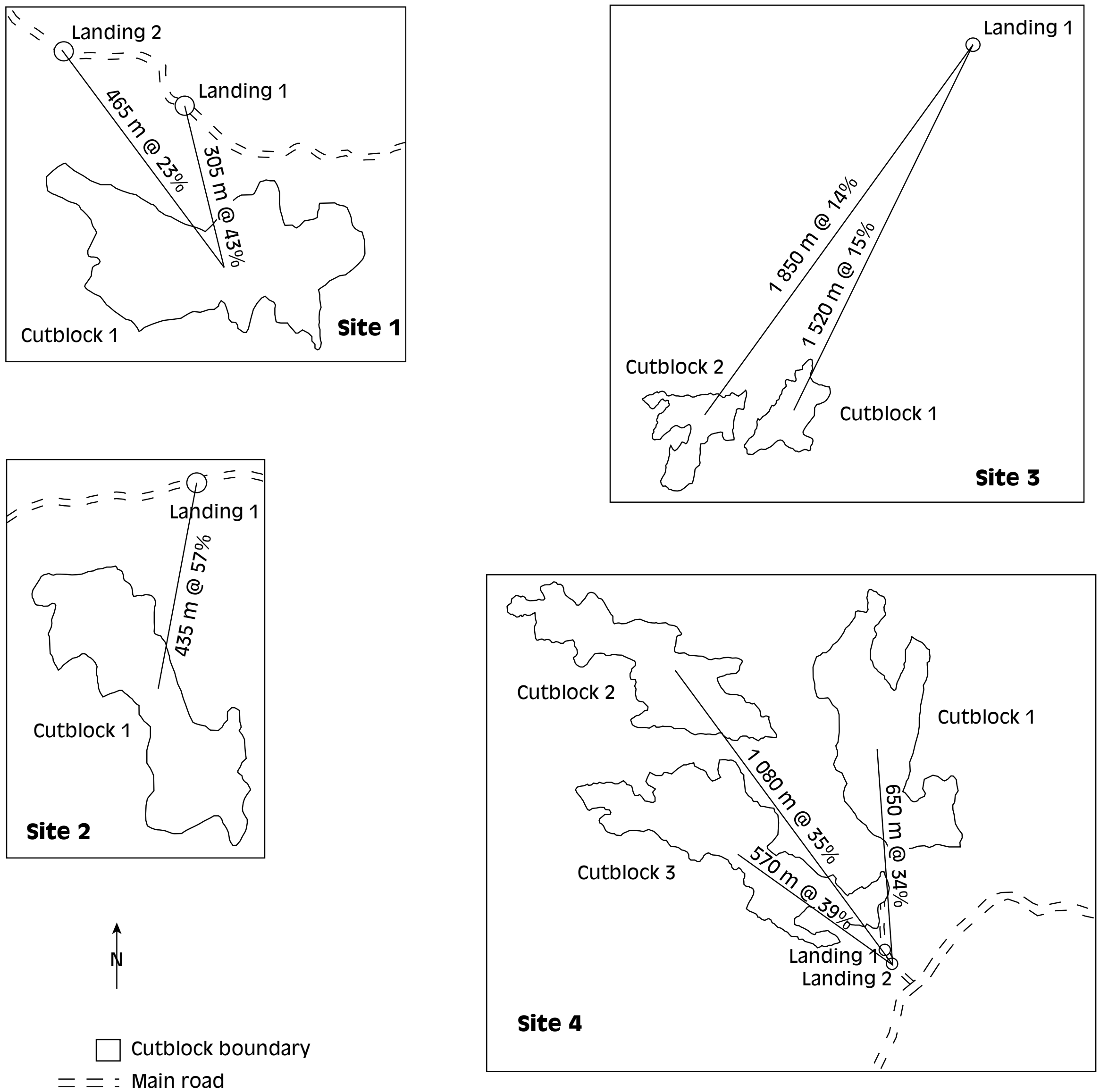
steep terrain, visual quality objectives, relatively small tree size, and the need to maintain wildlife and cultural heritage resources. The successful bidder, Transwest Timber, proposed to harvest the study sites with a Bell 214B "Big Lifter" helicopter. Harvesting operations were scheduled to begin during late summer to take advantage of favourable weather and daylight conditions.

Figure 1 illustrates the layout of the sites, and presents the cutblock-to-landing flight distances and slopes. See Appendix I for a description of helicopter yarding distance.

Sites 1 and 2 each consisted of one cutblock. A seed tree system was prescribed at both sites to meet concerns about ongoing colluvial activity and regeneration difficulty. About 4 m^2/ha (10%) of basal area of dominant and co-dominant Douglas-fir was retained uniformly throughout the cutblocks where pre-harvest stem distributions allowed. Site 1 utilized two 0.2-ha downslope landings which were 1.4 km apart. Site 2 utilized one downslope landing which was 0.6 ha in size.

Site 3 consisted of two cutblocks. Clearcutting was prescribed for both cutblocks. The cutblocks utilized one downslope landing which was approximately 2.4 ha in size and which was located in an existing gravel pit. Sites 1, 2, and 3 used the same service landing for helicopter refuelling and maintenance activities. It was located 4.3 km from Site 1, 1.7 km from Site 2, and 200 m from the downslope landing at Site 3.

Site 4 consisted of three cutblocks. A combination of clearcutting with retention of 2 to 4 Douglas-fir trees/ha, and irregular shelterwood consisting of uniform and group removal with a minimum residual basal area of 16 m^2/ha were prescribed for this site. This prescription addressed visual quality and root disease concerns. Group removal openings up to 0.2 ha, which were a maximum of 25 m perpendicular to the contour and 80 m parallel to the contour, were harvested. The cutblocks at Site 4 utilized two downslope landings—a 0.4-ha main landing and a 0.2-ha overflow landing. The service



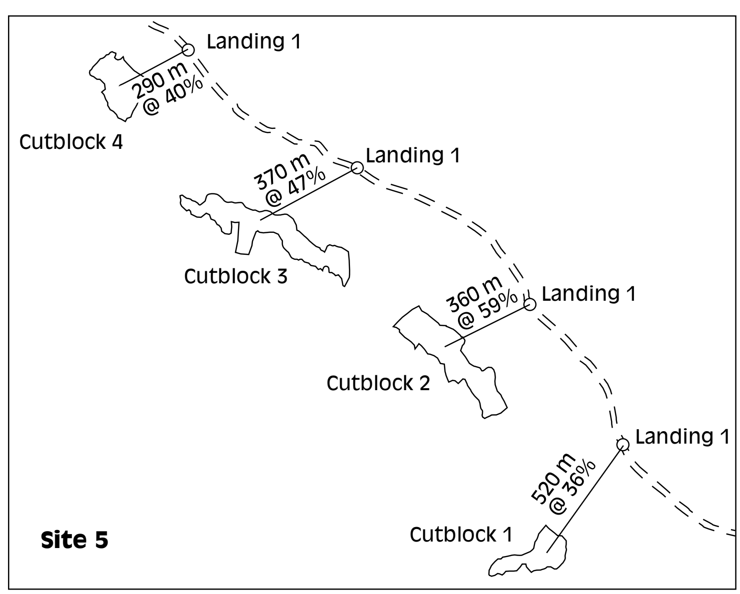


Figure 1. Layout of Sites 1–5. **Note:** Cutblock-to-landing flight path parameters are measured in horizontal distance and slope gradient from the centre of each cutblock to the corresponding main landing.

landing for Site 4 was located 2.6 km northeast of the main landing.

Site 5 consisted of four cutblocks. Clearcutting was prescribed for all cutblocks at this site. Each cutblock at this site utilized its own 0.2-ha downslope landing. The service landing for Site 5 was located about 3 km from Cutblock 1 at this site.

Helicopter specifications

The Bell 214B is a single-turbine, light-lift helicopter[1] and is one of the largest light-lift helicopters used for logging in British Columbia (Figure 2). Its rated payload is 8 000 lb. and its target payload during helicopter logging operations is typically 5 500–6 000 lb. in hook (choker) mode and 4 500–5 000 lb. in grapple yarding mode. Key specifications for the Bell 214B and other helicopters used for logging in British Columbia are shown in Appendix II. More information about the Bell 214B is presented in Dunham (2003).

Study methods

A FERIC researcher was on-site for most of the harvesting operations at Sites 1 and 4, and collected shift-level and detailed-timing information at both sites. Periodic visits were made to Sites 2, 3, and 5 to observe harvesting operations and to collect falling and yarding shift-level information. Shift-level information was supplied by the cooperators and included shift production reports, data summaries for the helicopter cycles, daily operating reports, and scaled volume data. During the yarding phase, FERIC frequently discussed the progress of the harvesting operation with Ainsworth and Transwest personnel to identify site, stand, layout, and organizational factors that influenced the helicopter's efficiency and productivity.

Harvesting productivities were calculated from shift-level time and volume data. Harvesting costs for the helicopter system were estimated using several sources. Costs for the Bell 214B helicopter were estimated using a modified version of the costing methodology in Guimier and Wellburn (1984), plus information from the Official Helicopter Blue Book and Helicopter Equipment Lists & Prices (HeliValue$, Inc. and Helibooks Ltd. 2004) and the 2004 Helicopter Annual (Helicopter Association International 2004) (Appendix III). A computer program was also used to help determine helicopter costs.[2] Hourly costs for other machinery involved in the harvesting operations were calculated using FERIC's standard costing methods (Appendix IV). Labour rates were based on the IWA British Columbia Coast Master Agreement using 2002 rates and then adjusted to reflect non-union circumstances. FERIC's cost estimates do not include stumpage or profit.

Results and discussion

Description of harvesting operation

Transwest was responsible for all yarding activities and stump-to-truck supervision. Falling and bucking were performed by Denny's Tree Falling Services, and loading was performed by Grand Island Logging. At the time of the study, all crews were experienced in helicopter logging operations. Sites 1, 2, and 3 were harvested consecutively starting in mid-August, and were completed by early

Figure 2. Bell 214B helicopter.

[1] Logging helicopters are commonly classified on the basis of their maximum rated payload as either light-lift (less than 10 000 lb.), medium-lift (10 000–15 000 lb.), or heavy-lift (more than 15 000 lb.).

[2] Aircraft Cost Evaluator, 2004 version, by Conklin and de Decker Associates.

November. However, harvesting operations at Sites 4 and 5 were not continuous because Site 4 was located in critical mountain goat habitat and harvesting was prohibited during goat mating season (mid-to-late December to early January). As a result, harvesting began on Site 4 in early November, and shifted to Site 5 in mid-December to accommodate the wildlife constraints. Following a break of 11 days in late December and early January for Christmas and maintenance, yarding on Site 5 resumed in early January and shifted back to Site 4 in early February. Harvesting was not completed at Site 5 because of a change in Ainsworth's harvesting plans.

Falling

Cross-slope hand-falling was done by a crew of 1 to 5 fallers. Only limited in-woods bucking and limbing were done on Sites 1, 2, and 5. The reason for leaving trees "whole" or full length at Sites 1 and 2 was a result of miscommunication between Transwest and the falling contractor. This was corrected for Sites 3 and 4 where comprehensive in-woods bucking and limbing were done to reduce the amount of waste wood flown by the helicopter. At Site 5, time constraints limited the amount of in-woods manufacturing that could be done.

At Sites 1 and 5, the fallers hiked into and out of the work areas, which required 10 to 15 minutes each way. On Sites 2, 3, and 4, the fallers were ferried into their worksites at the beginning of each shift by a Bell 206B Jet Ranger helicopter. Then, they hiked 20 to 30 minutes out of the cutblocks at the end of each shift. The Bell 206B helicopter was based in Lillooet and required one hour of flight time per shift for each of the sites.[3]

At Sites 1 and 2, falling was completed before yarding began. However, at Sites 3, 4, and 5, falling was performed concurrent with the yarding phase to minimize the risk of heavy snow accumulations on the felled timber.

Yarding

The Bell 214B yarding helicopter was equipped with a single 20-kg hook and 45-m longline. Additionally, a 400-kg grapple was used intermittently to yard wood when the rigging and landing crews needed more time to clear landings or pre-set turns. The yarding crew consisted of flight, helicopter maintenance, rigging, and landing crews. It comprised 12 members, except on Site 4 where there were only 11 members (Table 2). A woods foreman was also on-site during the yarding phase. As well, two loader operators performed log clearing, decking, and loading activities, except on Site 3 where only one loader operator was used for most of the harvesting operation.

The flight crew consisted of the Bell 214B pilot and co-pilot, and the maintenance

[3] A flight time minimum of one hour was incurred for any shift requiring the support helicopter.

Table 2. Crew complement for the yarding phase

Crew description	Sites 1, 2, 3, and 5		Site 4	
	Crew position	Crew members (no.)	Crew position	Crew members (no.)
Flight crew	Bell 214B pilot	1	Bell 214B pilot	1
	Bell 214B co-pilot	1	Bell 214B co-pilot	1
Rigging crew	Hooktender	5	Hooktender	4
Landing crew	Chaser	2	Chaser	2
	Landing bucker	2	Landing bucker	2
Maintenance crew	Flight engineer	1	Flight engineer	1
Total crew		12		11

crew consisted of one flight engineer. Helicopter maintenance equipment included a service truck, a standard highway fuel tank, and an aircraft refuelling system. Maintenance shift lengths varied daily depending on the number of hours flown per shift. Usually, the engineer performed 2 to 3 hours of post-shift maintenance, and was on-site for about 6 hours per shift during the yarding operations to carry out refuelling and in-shift maintenance checks. All routine post-shift maintenance was done at Lillooet Airport where the helicopter returned each night. Major maintenance or repair work was done at Transwest's base hangar in Chilliwack, B.C., which was approximately a 40-minute flight from the site. On average, the Bell 214B returned to Chilliwack about every 120 to 150 flight hours for major maintenance and repairs, which took 1 to 4 days on each occasion.

Available daylight allowed the rigging crews to work 12-hour shifts on Sites 1 and 2, 11.5-hour shifts on Site 3, 9-hour shifts on Site 4, and 9.5-hour shifts on Site 5. For the entire project, the rigging crew had an average effective shift length of 10.5 hours.

The rigging crew consisted of five hooktenders, except for Site 4, where only four hooktenders were used. The hooktenders usually worked individually to assemble, set, and hook an average of 2 to 5 turns per cycle.[4, 5]

Yarding progressed from the top down in all cutblocks. The hooktenders were deployed across the hillside to avoid working under the helicopter's flight path. The helicopter followed a fixed rotation among the rigging crew and generally flew to each hooktender two or three times per cycle. However, the number of consecutive turns set by each hooktender often varied depending on terrain difficulty, log availability, snow conditions, and prescription. Generally, hooktenders working in clearcuts yarded more consecutive turns than when working in partial cuts.

The 214B distributed chokers to each hooktender and returned an average of 10 choker bundles, or about 50 chokers, to the riggers each yarding cycle. At the end of each cycle, the helicopter returned to the service landing for 10 to 15 minutes, during which a "hot" refuelling (i.e., refuelling while the engine is running) was performed. Following every fourth yarding cycle, the Bell 214B was shut down for 45 to 60 minutes for mechanical inspection.

Like the falling crew, the rigging crew hiked into and out of the work areas on Sites 1 and 5 at the beginning and end of each shift. This took 20 to 30 minutes per shift depending on weather conditions. On Sites 2, 3, and 4, the rigging crew was ferried into the work areas by a support helicopter and then hiked out at the end of the shift. The hike took about 15 to 30 minutes on Sites 2 and 3, and 30 to 60 minutes on Site 4, depending on weather conditions. Typically, the support helicopter began flying the rigging crew to their worksites about 30 to 60 minutes prior to the start of yarding, to allow crews to pre-set turns and prepare for yarding operations.

Loading

The scheduled shift length for the landing and loading crews varied from site to site but was typically between 10 and 12 hours. At four sites, one front-end loader and one hydraulic log loader were used to clear, deck, and load logs. At Site 3, the wheel loader worked alone for much of the time. The hydraulic loader was brought in towards the end of the yarding operation on this site to assist the wheel loader with loading trucks.

[4] A yarding turn is defined as the sequence of activities required to transport one load of logs from the stump to the landing. A turn consists of the following elements: flying from the landing to the hook-up site (fly empty), securing the load of logs (hook up), lifting the turn above the stand's canopy before beginning forward flight (break out), flying from the hook-up site to the landing with a load of logs (fly loaded); and placing and releasing the logs on the landing (unhook).

[5] A cycle is defined as the period of continuous flight operations between refuelling and/or maintenance breaks, during which a series of turns is yarded. In helicopter logging, typically 25–45 turns are yarded in a 50–90-minute cycle.

Harvesting productivity and cost

A total scaled volume of 32 026 m^3 was harvested from the five study sites. Overall, the falling phase averaged 91 m^3 per shift with production (SWP), the helicopter yarding phase averaged 260 m^3/SWP, and the loading phase averaged 133 m^3/SWP. The total per-unit stump-to-truck harvesting cost was estimated at \$80.17/m^3 (Table 3). Yarding comprised the largest portion of the total harvesting cost at 80%, followed by loading and processing at 14% and falling at 6%.

The average cost of the yarding phase in this study is comparable to other recent FERIC helicopter logging reports (Dunham 2002, 2004). However, the average falling cost in this study is considerably lower than in these other recent studies because limited in-woods log manufacturing was carried out on three of the five sites. Conversely, loading and processing phase costs were higher for this study because log merchandizing was done in the landing prior to trucking, and only one loader was used most of the time at Site 3.

Costs presented in this report are estimated by FERIC using assumptions that are not influenced by project-specific circumstances such as contractor or project economies of scale and market and business conditions. These circumstances may have a considerable impact on logging costs and, as a result, the contractor's or licensee's actual costs may vary significantly from FERIC's estimates. Appendix V illustrates the effect that changing key cost variables can have on the helicopter's hourly operating cost.

Falling

Falling began in late August and continued until late January. In 94 falling shifts during this period, a crew varying in size from 1 to 5 fallers worked a total of 351 faller shifts and 2 409 hours (including hiking or flying to and from the felling sites and in-shift delays). Based on a net volume of 32 026 m^3, each faller produced an average of 91.2 m^3/6.5-hour shift (Table 4). The primary factors affecting falling productivity were steep and difficult falling ground, in-woods manufacturing regimes, and long hikes to and from worksites. However, the selection prescriptions used in this study appeared to have little effect on falling productivity.

Falling productivity was highest on Site 4, where each faller produced an average of 116.9 m^3/6.5-hour shift. Fallers worked intermittently on this site between late October and mid-December, and again for a short time in January. Although tree size, terrain, and time required to walk or fly in

Table 3. Estimated costs of falling, yarding, and loading

	Falling (\$/m^3)	Yarding (\$/m^3)	Loading (\$/m^3)	Total (\$/m^3)
Prime costs				
Yarding helicopter		44.31		44.31
Support helicopter	0.57	0.92		1.49
Other equipment		3.47	3.89	7.36
Chainsaws	0.60	0.22	0.48	1.30
Choker replacement		0.11		0.11
Labour	2.57	6.86	5.51	14.94
Subtotal	3.74	55.89	9.88	69.51
Other costs				
Mobilization		0.12	0.05	0.17
Crew transport	0.24	0.45	0.35	1.04
Supervision		1.41		1.41
Crew room and board	0.41	1.49	0.64	2.54
Overhead	0.11	2.18	0.27	2.56
Project costs		2.94		2.94
Subtotal	0.76	8.59	1.31	10.66
Total	4.50	64.48	11.19	80.17

Table 4. Shift-level productivities for the falling, yarding, and loading phases

	Site 1	Site 2	Site 3	Site 4	Site 5	All sites
Falling						
Scheduled shifts worked (no.)	12	15	31	26	10	94
Non-productive shifts (no.)	0	0	6	25	19	50
Average fallers per scheduled shift worked (no.)	4.5	3.0	4.3	3.1	3.7	3.7
Total productive faller-shifts worked (no.)	54	45	134	81	37	351
Production per 6.5-h faller shift (m^3)	94.5	60.7	57.0	116.9	114.6	91.2
Yarding						
Logging helicopter						
Potential shifts (no.)	16	10	31	44	46	147
Non-operating shifts (no.)	0	0	3	4	16	23
SWP[a] at other sites (no.)	0	0	0	1	0	1
SWP[a] at study site (no.)	16	10	28	39	30	123
Average flight-hours/productive yarding shift (no.)	7.0	7.2	7.2	5.1	5.3	6.0
Production per SWP[a] (m^3)	319.1	273.2	272.8	242.8	236.1	260.4
Loading						
Scheduled shifts worked by hydraulic loader (no.)	17	9	9	38	33	106
Scheduled shifts worked by the wheel loader (no.)	14	11	35	41	33	134
Average loaders per shift (no.)	1.8	1.8	1.3	1.9	2.0	1.8
Total loader shifts worked (no.)	31	20	44	79	66	240
Production per productive loading shift (m^3)	167.4	136.6	177.6	119.8	107.3	133.4

[a] SWP = shifts with production.

and out of this site were comparable to the other sites, falling production may have been increased because an in-woods quality control person assisted fallers with falling and bucking decisions on this site.

Site 5 also had high falling productivity (114.6 m^3/6.5-hour faller shift). Falling on this site was performed on 10 days during mid-December and mid-January. No in-woods manufacturing was carried out at this site, which likely helped to increase per-shift falling production compared to the other sites despite poor weather and deep snow.

Site 1 was felled between mid- and late August. Falling productivity at Site 1 (94.5 m^3/6.5-hour shift) was higher than at Sites 2 and 3 (60.7 and 57.0 m^3/6.5-hour shift, respectively) because, similar to Site 5, limited in-woods manufacturing was done at this site. Therefore, less "falling" time was required per tree.

Site 2 recorded a falling productivity, based on a net volume of 2 732 m^3, of 60.7 m^3/6.5-hour shift. Although this site and Site 1 were both seed tree prescriptions, falling productivity was substantially lower on this site. This is due in part to the fallers spending slightly more time per shift hiking or flying into and out of their work areas (7% vs. 5% at Site 1). However, the large productivity difference is mostly unexplained because close monitoring was not carried out at Site 2.

Site 3 had the lowest falling productivity at 57 m^3/6.5-hour shift. The proportion of shift time spent walking or flying to and from worksites each shift was much greater at this site (15% vs. 7% or less for other sites). As a result, productive falling time at this site was about 0.5 hours less per shift than at Site 2. Additionally, the level of in-woods manufacturing was higher compared to Sites 1, 2, and 5.

Average falling productivities in this study were substantially higher than falling productivities of 39.0 m^3/6.5-hour shift for 20-m-wide strip cuts along the contour and 54.8 m^3/6.5-h shift for clearcuts reported by

Boswell (2004). The major factors affecting productivity in Boswell's study were similar to this study. These included long hikes by fallers to and from worksites (19% of total time in the clearcut and 9% of total time for the partial cut); delays for planning and reconnaissance; and steep, difficult terrain.

Loading

Loading and processing began at the same time as the yarding phase and were completed shortly after yarding was finished. Two landing buckers worked a total of 136 shifts and 2 946 hours to process logs at the sites. The hydraulic loader worked 106 shifts (1 128 hours) and the wheel loader worked 134 shifts (1 420 hours) to load logs in the landings, for an average of 133 m^3/SWP for cleared, processed, and loaded wood. Loading and processing productivity was reduced because logs were carefully merchandized and sorted in the landing prior to loading and trucking to ensure that the logs were trucked to the appropriate mill. At the time of the study, Ainsworth's mills in the area were grade-specific (i.e., sawlog, peeler, and pulp) and widely separated.

Yarding

In total, 743.2 flight hours or 61% of potential yarding time[6] was spent yarding the project area[7] (Table 5) (Figure 3). Scheduled maintenance and refuelling time were estimated at 24% of total scheduled hours. Therefore, flight time and associated service activities accounted for 85% of the total hours potentially available for yarding. Additionally, 9% of potential shift time was lost to poor weather, 2% to unscheduled maintenance, and 4% to other incidental delays.

[6] Potential yarding time is based on an estimate of available daylight hours per shift, within a reasonable shift length of no greater than 12.5 hours in any given day.

[7] Transwest supplied the number of flight hours worked during the study, and FERIC estimated the distribution of non-flight hours from field notes and discussions with Transwest.

Figure 3. Project shift-level time distribution.

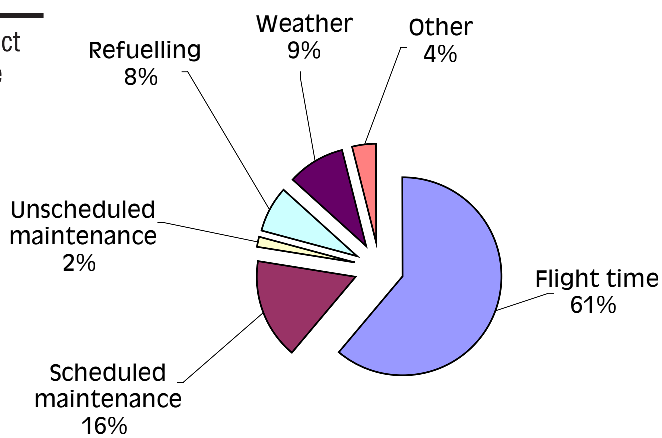


Table 5. Shift-level time distributions for productive shifts

	Site 1	Site 2	Site 3	Site 4	Site 5	All sites
Flight time						
Shifts with production (no.)	16	10	28	39	30	123
Flight hours per productive shift (h)	7.0	7.2	7.2	5.1	5.3	6.0
Non-flight time						
Scheduled maintenance (h)	27.4	19.2	50.8	56.8	43.7	197.9
Refuelling (h)	14.6	10.0	28.2	24.6	19.8	97.2
Unscheduled maintenance (h)	8.4	0.0	1.6	11.0	0.9	21.9
Weather (h)	0.0	9.2	23.9	18.0	64.2	115.3
Other (h)	13.9	8.4	14.2	5.5	3.7	45.7
Subtotal (h)	64.3	46.8	118.7	115.9	132.3	478.0
Total scheduled hours (h)	175.5	119.2	321.3	315.3	289.9	1221.2
Total flight hours (h)	111.2	72.4	202.6	199.4	157.6	743.2
Ratio of flight hours to total potential hours (%)	63	61	63	63	54	61

The ratios of flight time to total hours were very similar for Sites 1, 2, 3, and 4, ranging from 61 to 63% of total potential hours, while combined flight and associated service activities for the same sites accounted for 85 to 89% of total potential hours. This flight-hour ratio is likely a reasonable estimate of the long-run average because of the duration of this project. Site 5 was an exception with a flight-hour-to-total-hour ratio of only 54% and a combined flight hours and associated service activities ratio of only 76%. Yarding was carried out in mid-December and ended in mid-January. The low ratio on this site is a direct result of heavy snowfall and cold weather. However, this was not unexpected because large weather delays are typical in winter months, especially when working in the interior of British Columbia.

In a helicopter yarding study on the British Columbia coast during the early spring, the Bell 214B achieved a flight-hour-to-total-hour ratio of 66%, slightly higher than the ratios calculated in this study for Sites 1 through 4 (Dunham 2003).

The Bell 214B extracted a total payload of 76 059 200 lb., yielding an average weight-to-volume conversion of 2 375 lb. based on 32 026 m^3 net scaled volume.[8] On average, the helicopter flew 6 hours or 5 yarding cycles/shift and produced approximately 260 m^3/SWP and 43 m^3/flight-hour (hook and grapple yarding production could not be separated) (Table 6). Yarding turn times averaged 3 minutes, resulting in 19.8 turns/flight-hour with an average abort rate of 3.3%.[9] The Bell 214B achieved an average load factor of 65%, less than the desired average of 70% set by Transwest for this operation.[10]

The average yarding productivity of 43.1 m^3/flight-hour for this study was less than the cooperator's expectations. Transwest

[8] In the helicopter logging industry, the logging helicopter's productivity per flight-hour is typically expressed in terms of weight rather than volume. Weight is measured directly whereas volume is derived from weight, and the conversion varies from site to site due to differences in species composition, wood density, cull factor, and waste allowance.

[9] An "abort" is described as discontinuing a turn (lift) due to excessive load weight, hang-ups, or mechanical difficulties.

[10] Load factor is the actual turn payload divided by the helicopter's rated payload, expressed as a percentage.

Table 6. Yarding production summary

	Site 1	Site 2	Site 3	Site 4	Site 5	All sites
Production totals						
Cycles flown[a] (no.)	83	54	152	150	118	557
Turns yarded (no.)	2 579	1 308	3 103	4 014	3 700	14 704
Weight yarded (lb.)	12 801 200	6 708 500	16 158 800	20 690 400	19 700 300	76 059 200
Volume yarded (m^3)	5 105	2 732	7 637	9 468	7 084	32 026
Weight-to-volume Conversion factor (lb./m^3)	2 508	2 456	2 116	2 185	2 781	2 375
Production per SWP						
Cycles (no./SWP)	5.5	5.4	5.8	4.4	4.1	4.9
Turns (no./SWP)	171.9	130.8	119.3	125.4	127.6	129.0
Weight yarded (lb./SWP)	853 413	670 850	621 492	608 541	679 321	667 186
Volume yarded (m^3/SWP)	340.3	273.2	293.7	278.5	236.1	260.4
Production per flight-hour						
Turns (no./flight-hour)	23.2	18.1	15.3	20.1	23.5	19.8
Weight (lb./flight-hour)	115 119	92 659	79 757	103 763	122 906	102 340
Volume (m^3/flight-hour)	45.9	37.7	37.7	47.5	45.0	43.1
Production per turn						
Average turn time (min)	2.6	3.4	3.9	3.0	2.6	3.0
Weight (lb./turn)	4 973	5 170	5 205	3 883	5 263	5 173

[a] Number of cycles flown was estimated by FERIC based on detailed-timing information.

expected average turn times in this project of 0.5 to 1 minute faster (depending on the site) than the average turn times achieved, and also expected an average load factor of 70%. Site 4 was the exception, out-performing the anticipated turn time estimate by approximately 0.4 minutes. A 0.5-minute decrease in total turn time and a 5% increase in load factor would have yielded a yarding productivity of 130 000 to 135 000 lb./flight-hour, or 27 to 32% higher than the study average. This would represent a volume production of 55 to 58 m^3/flight-hour based on the study weight-to-volume conversion factor, or an increase of 12 to 15 m^3/flight-hour over the actual productivity.

Site 1 achieved the highest shift-level productivity of all the sites at 340 m^3/SWP, or 14 to 31% higher than the other sites. The higher shift production for this site is likely in part the result of the relatively high ratio of flight hours to total hours (63%) compared to the other sites. The flight hour ratio was high because no weather-related downtime occurred during the yarding phase on this site—Site 1 was harvested during late summer when weather conditions are typically optimal for helicopter logging. The combination of good weather and long hours of daylight resulted in a longer average shift length and better opportunity to optimize flight hours per shift compared to the other sites which were yarded during the fall and winter months. However, the hot, dry conditions during yarding on Site 1 also created heavy dust in the landings and increased crew fatigue.

Site 4 achieved the highest volume per flight-hour at 47.5 m^3/flight-hour. Site 4 had a relatively low average turn time, a result of mid-range yarding distances and acceptable flight path slopes (<35%). Also, Site 4 had the second lowest weight-to-volume conversion factor owing to comprehensive in-woods manufacturing, which resulted in a relatively low cull factor.

Detailed-timing study

FERIC performed a total of 19 flight hours (2.5% of total flight time) of detailed timing on Sites 1 and 4 (Table 7). On Site 1 (seed tree prescription), turn times for the detailed-timing period averaged 2.3 minutes at an average yarding distance of 367 m. An average turn consisted of 3.2 logs. In comparison, on Site 4 with patch cut and clearcut prescriptions, turn times averaged 3 and 3.4 minutes at average yarding distances of 708 and 1 170 m, respectively. An average turn consisted of 3.2 logs and 3 logs, respectively, for the patch cut and clearcut. Hookup and breakout comprised the largest portion of the turn at all of the sites, varying from 37 to 48% of total turn time. Overall, yarding cycle length varied from 68 to 95 minutes and averaged 80 minutes.

The turn time distribution in this study was different from the distribution reported in Dunham (2003), where less time per turn was spent hooking up and breaking out the

Table 7. Helicopter yarding detailed-timing results by block and treatment

Site and treatment (no.)	Turns (no.)	Average yarding distance (m)	Average turn payload (lb.)	Fly empty (min.)	Hook up and break out (min.)	Fly loaded (min.)	Unhook (min.)	Total delay-free turn time (min.)
Site 1								
Seed tree	250	367	4 850	0.42	1.01	0.51	0.31	2.25
% of turn time	-	-	-	19	45	22	14	100
Site 4								
Clearcut	46	1 170	5 818	0.83	1.27	1.01	0.27	3.37
% of turn time	-	-	-	25	37	30	8	100
Patch cut	140	708	5 334	0.47	1.43	0.78	0.30	2.98
% of turn time	-	-	-	16	48	26	10	100

turn (40%) and more time was spent flying empty (26%). Flight distances were shorter in Dunham (2003) than in this study, resulting in lower average travel speeds owing to the effects of acceleration and deceleration. Additionally, hookup and breakout time in this study was longer, in part because the average stand height was taller than in Dunham (2003). As a result, the helicopter required more time during hookup and breakout to lower the hook and then lift out the turn. Because the residual trees at Sites 1 and 4 were not well rooted, additional care was required to avoid hitting standing trees with the turn. The need to have more control over turns during breakout favoured the use of a 45-m instead of a 60-m longline.

Factors affecting helicopter yarding productivity

The cooperators identified the following factors as having influenced the helicopter's productivity in this project:

- high cull factors
- undersized or poorly designed landings
- the retention prescriptions
- poor weather
- long flight distances
- use of only one loader
- dust control problems.

Cull factor

Cull factor is the weight of unmerchantable material flown to the landing, expressed as a percentage of the total weight of wood flown. For interior Douglas-fir stands, helicopter logging contractors typically expect a "clean" (i.e., free of cull and stand defect) weight-to-volume conversion ratio of between 1 700 and 1 950 lb./m^3 and a cull factor of 4 to 7%. Transwest estimated an initial weight-to-volume conversion factor of about 2 250 lb./m^3 for this project, based on a stand defect allowance of 12% and a cull factor of 6 to 7%. However, the average conversion ratio for this study was higher than expected at 2 375 lb./m^3. FERIC estimated the cull factor at 15% for this project, based on a "clean" log weight–to–volume conversion factor of 1 800 lb./m^3 and a stand defect allowance of 12%.[11]

The difference between the expected and actual conversion factors was largely owing to leaving the trees full length and/or mostly unlimbed at Sites 1, 2, and 5. Conversion factors for Sites 1, 2, and 5 were 2 508, 2 456, and 2 781 lb./m^3, respectively. These were higher than for Sites 3 and 4, which had conversion factors of 2 116 and 2 185 lb./m^3, respectively, and where intensive in-woods manufacturing was performed. Frozen snow accumulations on felled timber at Site 5 probably also contributed to the higher per-unit weight at the site. The results for Sites 3 and 4 suggest that the high conversion factors for Sites 1, 2, and 5 could have been substantially reduced with more intensive in-woods manufacturing.

According to Adamovich (1979), 20 to 25% of the total weight of a "whole" dry interior Douglas-fir tree consists of branches and a greater-than-10-cm top (inside bark). Using the average weight-to-volume conversion factor for Sites 1 and 2, where trees were largely unmanufactured, reverse calculations suggest that the unmerchantable branches and top account for about 18% of the "full" tree weight. In other words, almost one-fifth of the weight yarded from these sites was waste that generated no revenue. This illustrates the need for careful consideration of how much in-woods manufacturing is carried out.

Landing size and design

Landings at Sites 1 and 5 were all pre-existing cable yarding landings. The landings ranged in size from 0.2 to 0.4 ha, and in general were not large enough to accommodate the helicopter's daily production. Loading and processing activities were often restricted because of limited space.

[11] Dobie and Wright (1979). Green wood density for interior Douglas-fir is approximately 2% less than coastal Douglas-fir. For this study, FERIC assumed a weight-to-volume conversion factor of approximately 1 800 lb./m^3 based on information from helicopter logging contractors for Douglas-fir.

At Site 1, yarding and loading could not be done at the same time in the same landing. As a result, loading activities were often delayed or the helicopter had to yard logs to the alternate landing, regardless of flight distance or other limiting factors. Additionally, because the main road into Landing 2 was located through the centre of Landing 1, vehicle access to Landing 2 was restricted during active yarding. This resulted in increased congestion and fewer trucks being loaded in Landing 2 .

Similarly, at Site 4, the landings were too small. Therefore, the turns had to be yarded to an overflow landing, and then forwarded with the wheel loader to the main landing for processing and loading. Additionally, several trees were left bordering the landings for this site, which restricted flight path options for the helicopter.

Adding to the difficulties experienced with the log landings, the service landings used for Sites 1, 4, and 5 were between 2.6 and 4.3 km from their respective cutblocks. Although Transwest was satisfied with the size and general design of these service landings, the long flight distances to the service landings added unproductive flight time to the project.

Retention prescriptions

Transwest believed yarding productivity was affected by the harvest prescription. For example, Transwest felt the seed tree prescription at Sites 1 and 2 was not well suited to helicopter logging because trees at both sites were poorly rooted. As a result, the helicopter's downwash blew over many of the residual trees and reduced the effectiveness of the prescription.

The detailed-timing results show that average turn weights were 9 to 17% lower in the seed tree prescription than in the patch cut and clearcut prescriptions. The seed tree prescription required the helicopter to dead-lift[12] turns above the stand's canopy before beginning forward flight to minimize the risk of damaging or knocking over residual trees. A helicopter requires more torque for dead-lifting compared to controlled descent, and the added torque requirements required payloads to be reduced to prevent unacceptable fatigue on the helicopter. Turn payloads at Site 1 were further decreased because trees were felled on top of each other, making breakout more difficult.

The detailed-timing results also show that turn times in the patch cut units at Site 4 were 32% longer than turn times in the clearcut units when flight distance was standardized. The increase was mainly attributed to a longer hookup and breakout time, owing to the narrow, rectangular shape of the patch cuts which limited the 214B's ability to maneuver within the unit during hookup. Because the 214B has no backward flight capabilities, the helicopter had to climb above the stand's canopy before it could turn around in the units. Average turn payload was also 8% less for the patchcuts compared to the clearcut. Again, the turn weight difference is also likely a result of having to dead-lift turns, because the helicopter had to continually lift turns from along the lower tree line in the patch cuts. Finally, the narrow patch cuts complicated safe placement of hill crews.

Weather conditions

Poor weather accounted for 9% of total potential flight time. The harvest season was closely linked to the proportion of weather-related downtime experienced by the helicopter. At Site 1, which was yarded during early September, no weather-related downtime was encountered. At Sites 2, 3, and 4, which were harvested during the fall and early winter, weather-related downtime ranged from 6% to 8%. The amount of weather-related downtime experienced on Site 4 (6%) was less than expected according to Transwest. This site was comprised of several openings and the helicopter minimized the effects of poor weather by moving frequently between units. At Site 5, which

[12] Dead-lift is described as lifting a turn straight up from the ground to a height above the stand's canopy before beginning forward flight.

was yarded during December and January, weather-related downtime reduced the available flight time by 22%. Overnighting the helicopter at the Lillooet Airport during the winter months also likely added to the high percentage of lost time related to weather. The helicopter was frequently delayed from takeoff at the airport due to fog and/or snow, even though the worksites and service landings were clear.

Long flight distances

Transwest typically prefers to operate at flight distances of less than 1 000 m and slope gradients of not more than 35%. Overall, the effective average yarding distance for this project was approximately 800 m and the flight path slope gradient was 33%, both within Transwest's acceptable operating range. However, yarding distance and flight path slopes varied considerably between the project sites. For example, the effective average yarding distance for Site 3 was 1 708 m at 14%. As a result, the average turn time of 3.9 minutes was substantially longer than turn times experienced at the other sites.

Owing to the very long flight distances at Site 3, greater importance was placed on maximizing turn payload so grapple yarding was not done at this site. As a result, the flight hours potentially available each shift were reduced compared to the other sites, where it was common for the helicopter to grapple yard in the early morning and late afternoon while crews hiked or were flown into and out of worksites.

Use of only one loader

Transwest chose to use only one wheel loader for a majority of the log clearing and loading tasks at Site 3. The loader operator did not have enough time between yarding turns to clear the drop zone and lay the logs out for processing, so most of the yarded wood was cold-decked. As a result, landing buckers were idle for an estimated 50–60% of each active yarding shift. Futhermore, cold-decking resulted in the loader re-handling most of the yarded volume and left the loading phase incomplete when yarding was finished. Consequently, when yarding began at Site 4, the wheel loader and one landing bucker stayed behind for more than a week to complete processing and loading activities.

Lack of dust control

The weather conditions were hot and dry when Site 1 was harvested, and active yarding operations created very dusty conditions in both landings. The heavy dust created by the helicopter's downwash decreased visibility, especially during unhook activities. The loader in the active landing often had to stop working until the dust dispersed because it was difficult to locate the chasers. As a result, the dust reduced log clearing productivity and created potential safety hazards for the landing crew. The dust could have been controlled or eliminated by using a water pump to dampen the landings during the yarding phase.

Comparing alternative harvesting scenarios

Forest engineers and helicopter logging contractors often need to evaluate several harvesting scenarios for a site to determine the best option for a helicopter logging project. This study provided an opportunity to examine two alternatives in detail. Scenario 1 examines the costs and benefits of increasing the level of in-woods manufacturing during the falling phase at Sites 1, 2, and 5. Scenario 2 examines the effects of increasing the level of in-woods manufacturing and postponing yarding at Site 5 until the following spring.

The following major assumptions were used:

For Scenarios 1 and 2:

- Falling productivity was decreased by 25% at Sites 1, 2, and 5 as a result of greater in-woods manufacturing.
- Average cull factor was reduced from 15 to 7% (stand defect remained at 12%).
- The weight-to-volume conversion factor was 1 800 lb./m^3.

- Loading productivity was unchanged.
- Bucking productivity at the landings was increased by 10% as a result of greater in-woods manufacturing.

For Scenario 2 only:

- The yarding helicopter was able to find alternate winter work (i.e., scheduled annual flight hours were unchanged).
- Mobilization cost was doubled.
- Weather-related downtime for Site 5 was reduced to 6%.
- The reduction in weather-related downtime reduced the number of shifts required to yard Site 5, thereby reducing helicopter and service landing equipment ownership costs and crew transport, supervision, and room and board costs.

Table 8 compares the two alternatives with the actual outcome for this study.

Scenario 1 resulted in an estimated cost savings of $3.42/m^3 compared to the status quo. Although increased in-woods manufacturing resulted in a higher overall falling cost, the reduction in cull yarded to the landing increased the total merchantable weight–to–total weight per turn. As a result, increases in falling cost were more than offset by decreases in yarding and loading phase costs.

Scenario 2 resulted in an estimated cost savings of $3.54/m^3. By postponing yarding operations from December and January until the spring, it is estimated that 9 yarding shifts or 46.4 hours of weather-related downtime could have been eliminated, reducing weather-related downtime from 64.2 hours to 17.8 hours (or from 22% to 6% of the total scheduled time). If yarding had begun two months earlier and been completed by November, yarding costs would have been reduced by a further $0.17/m^3 because the additional costs for the second mobilization would not have been incurred.

Table 8. Estimated costs for Scenarios 1 and 2

	Scenario 1	Scenario 2	This study
Falling ($/m^3)	5.65	5.65	4.50
Yarding ($/m^3)	59.97	59.85	64.48
Loading ($/m^3)	11.13	11.13	11.19
Total ($/m^3)	76.75	76.63	80.17

Other alternative harvesting options that might also have been considered included:

- Using a double-hook system rather than a single-hook system. The overall turn abort rate for this project was 3.3% or 485 turns (2 506 956 lb.) aborted. Therefore, 12.1 flight hours or approximately $34 000[13] was lost to turn aborts.[14] The use of a double-hook system as opposed to a single hook would have enabled partial turn aborts (30 to 40% of turn weight lost) rather than complete aborts (100% of turn weight lost). The ability to retain 60 to 70% of the aborted turn weight would have saved an estimated $20 000–$24 000 over the course of the project. This savings would have covered the estimated capital cost of the double-hook system and likely resulted in future cost savings to the helicopter logging contractor.
- Maintaining consistent 90-minute yarding cycles. According to detailed-timing information, full yarding cycles varied in length from 68 to 95 minutes and averaged 80 minutes. Standardizing yarding cycle length to 90 minutes might have decreased non-productive flight time. Detailed-timing information indicates that the average refuelling time, including site-to-service landing flight, ranged from 10 to 15 minutes. According to shift-level information, the Bell 214B averaged 6 flight hours per yarding shift. Therefore, if the 214B had consistently flown 90-minute yarding cycles, a total of four round-trip flights to the service landing would have been required per shift, barring unforeseen problems. However, with 80-minute yarding cycles, the 214B had to fly an average of five round-trip flights to the service landing, adding 10 to 15 flight-minutes and a cost

[13] Based on an all-found yarding cost of $2 778.57/flight-hour (($64.48/m^3 × 32 026 m^3)/743.2 flight-hour).

[14] Assumes that only 50% of average turn time was lost per turn abort.

of \$300–\$400 per shift for refuelling. Over the course of the project, this translates into \$37 000–\$55 000 or \$0.01–\$0.02/m^3.

- Overnighting the yarding helicopter at the service landing. A total of 37.3 flight hours were incurred to fly the helicopter from the study area to overnight at the Lillooet airport. In addition, poor weather at the Lillooet airport during the winter months often delayed the helicopter's take-off time and thus reduced the number of flight hours available for yarding. The potential gain in available flight hours might have been sufficient to offset the extra costs for night security and increased travel time for the pilots.

In summary, increasing in-woods manufacturing at Sites 1, 2, and 5 would have likely produced the highest overall cost savings, but is only one of several alternatives that might have been considered. Ultimately, this analysis demonstrates the importance of exploring different alternative harvesting scenarios prior to committing to a harvesting approach.

Conclusions

Ainsworth harvested five sites in the Cayoosh Creek watershed with a light-lift helicopter to address steep terrain, visual quality, wildlife, and cultural heritage issues. A total of 32 026 m^3 was harvested by the Bell 214B helicopter from a mix of single-tree, variable retention, and clearcut units. The areas were felled over a six-month period in 351 falling shifts. The falling crew varied in size from 1 to 5 fallers and averaged 91.2 m^3/6.5-h shift. The Bell 214B helicopter completed yarding in 123 productive shifts and averaged 260 m^3/10.5-h shift. One hydraulic log loader and one wheel loader completed log clearing, decking, and loading activities in 240 shifts, averaging 133 m^3/10.6-h shift.

Detailed timing was performed for 19 flight hours. At Site 1 (seed tree prescription), turn times averaged 2.3 minutes at an average yarding distance of 367 m, and an average turn consisted of 3.2 logs. In comparison, at Site 4 turn times averaged 3.0 minutes at 708 m in the patch cut and 3.4 minutes at 1 170 m in the clearcut prescription. An average turn consisted of 3.2 and 3 logs, respectively, for the patchcut and clearcut. Overall, yarding cycle length varied from 68 to 95 minutes and averaged 80 minutes.

FERIC estimated the total cost of falling, helicopter yarding, and loading at \$80.17/m^3. Falling accounted for \$4.50/m^3 or 6% of the total cost. Falling costs reflect long hikes by fallers to and from their worksites, steep terrain, and overall a reduced level of manufacturing than is typical for most helicopter logging operations. Loading and processing accounted for \$11.19/m^3 or 14% of the total cost. Loading costs were relatively high as a result of small landing sizes, design inefficiencies, and careful log merchandizing at the landing prior to trucking. Helicopter yarding accounted for \$64.48/m^3 or 80% of the total harvesting cost, with the cost of the logging helicopter alone at \$44.31/m^3 or 55%.

The key factors affecting yarding productivity and cost were high cull factor, landing size and design inefficiencies, retention prescriptions, poor weather conditions, long flight distances, use of only one loader, and lack of dust control.

Implementation

The results of this study reflect some of the operational challenges associated with harvesting with light-lift helicopters in clearcut and retention prescriptions in the interior of British Columbia. Important considerations for planners include:

- Effects of in-woods log manufacturing on helicopter yarding. It is important to carefully analyze the effects of in-woods manufacturing on overall harvesting cost before committing to a processing/bucking framework. FERIC estimated cull factor for this study at 15%,[15] which is

[15] Based on a 12% stand defect and a typical weight-to-volume conversion factor of 1 800 lb./m^3.

more than double the commonly accepted range. Cull factor was inflated because trees at Sites 1, 2, and 5 were left full-length and largely unlimbed. While falling productivity increases and cost decreases as the level of in-woods manufacturing decreases, the reverse is true for helicopter yarding productivity and cost.

- Effects of landing size and design on loading and manufacturing. During landing construction, it is worthwhile to consider cost-effective methods to maximize available landing space, especially for small landings. Loading and processing activities at Sites 1 and 4 in this study were often restricted because of limited landing space. Unfortunately, the landings at Site 1 could not be made larger because they bordered riparian areas. In situations like this where small landings cannot easily be enlarged, it is important to consider what type of loader is best suited to the landing. A hydraulic log loader is often more efficient in small landings than a wheel loader because it is better able to lay out logs for processing as well as load log trucks. Finally, it is important to ensure that log truck availability and scheduling complements rather than hinders the helicopter logging operation.
- Effects of harvesting prescription on helicopter yarding. During planning and scheduling activities, it is important to take into account the potential time and payload consequences associated with variable retention prescriptions. Detailed-timing information showed that yarding productivity was affected by harvesting prescription. In this study, average turn payloads were substantially lower in the seed tree units compared to the patch cut units, and patch cut units had lower average turn weights than clearcut units. Furthermore, average turn times in the clearcut units were notably less than in the patch cuts when flight distances were standardized.

  It is also important to consider the capabilities of the logging helicopter in relation to the demands of the prescription. In this study, for example, the patch cuts (Site 4) were narrow and rectangular in shape, which limited the 214B's ability to maneuver within the unit. As a result, turn times were increased because the helicopter had to climb above the treeline to turn around. A logging helicopter with backward flight capabilities but similar lift capabilities may have been better suited to harvesting the patch cuts in this study.
- Effects of weather on helicopter yarding. During yarding at Site 1, weather conditions were hot and dry, resulting in crew fatigue and heavy dust. Hot weather in mountainous areas can also have a considerable impact on a helicopter's load capacity. However, this was not a factor in this study because the 214B was originally designed for "hot and high" operating conditions. Conversely, winter weather conditions (fog and snow) during yarding at Site 5 resulted in a 22% loss of available flight time. When possible, schedule harvesting for the most favourable period to reduce downtime or production penalties.
- Effects of project size on overall costs. It is important to consider the effect of economies of scale on a project's overall cost. Generally, tendering larger-volume helicopter-logging projects comprised of one or several sites within close proximity to each other can reduce overall harvesting cost. This study details a six-month-long helicopter logging project. As a result of the relatively long duration of this project, equipment mobilization and helicopter ferrying costs accounted for less than 1% of the total harvesting cost—less than in other recent FERIC helicopter-logging studies where mobilization costs accounted for as much as 3% of total cost.

- Ensure the equipment complement is adequate to handle the volume being yarded. The use of only one loader at Site 3 required logs to be cold-decked and resulted in the landing buckers being idle for more than 50% of shift time. Consequently, the crew and equipment complement at Site 4 was less than optimal for the first few weeks of operation because some of the loading crew had to stay at Site 3 to complete processing and loading activities there.

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Appendix I

Estimating yarding distance for helicopter logging operations

This appendix is intended for forest engineers who are charged with planning and laying out cutblocks for helicopter logging projects.

Yarding distance is an important consideration when evaluating the feasibility and estimating the productivity and cost of a proposed helicopter logging project. However, estimated yarding distance for a given project can vary substantially depending on how the estimator interprets or "measures" yarding distance. To avoid confusion, therefore, it is important for the field engineer, supervisor, and heli-logger to have a common understanding of "yarding distance" when discussing proposed helicopter logging projects.

Typically, "yarding distance" (the distance the helicopter travels between the hookup site and the landing) can be defined in the following ways (see Figure A-1):

- Horizontal — the straight-line distance between the hookup site and the landing, measured as a horizontal (i.e., slope-corrected) distance.
- Slope ("chord") — the straight-line distance between the hookup site and the landing, measured along the slope.
- Flight distance — the total distance flown by the helicopter between the hookup site and landing, measured along the actual flight path.

In FERIC's helicopter logging reports, yarding distance is always defined as the horizontal straight-line distance between the hookup site and landing. FERIC adopted this definition because forest engineers traditionally use horizontal distance to describe yarding distances for other harvesting systems, and because horizontal distances and elevation changes can be measured directly from topographic maps and converted to slope (or flight) distance if necessary. Usually FERIC reports also present the elevation change and/or apparent slope, in combination with horizontal yarding distance, to fully describe the helicopter's typical flight path.

"Average yarding distance" (AYD) is an estimate of a helicopter logging project's average effective flight distance. Figure A-2 illustrates the method FERIC uses to calculate AYD for a helicopter logging operation consisting of more than one cutblock and/or harvest opening. In this situation, horizontal distances are measured from the centre of each unit to the centre of the landing(s) and then weighted by opening area or volume to calculate an effective, or "average", horizontal yarding distance for the entire project. The same technique is applied to estimate average vertical distances and average straight-line flight-path slope for the project.

It is stressed that straight-line distance (horizontal or slope) underestimates actual yarding or flight distance because in practice the logging helicopter's flight path between the hookup site and the landing is seldom perfectly straight. Provided there are no obstacles or hazards that prevent the logging helicopter from following the most direct path, however, straight-line distance reasonably approximates yarding distance for gentle and moderate slopes. While slope distance may be more accurate than horizontal distance when flight-path slopes exceed approximately 15%, the differences are relatively minor and FERIC considers horizontal distance to be the most practical measure of yarding distance for slopes up to 35–40%.

When the slope along the straight-line path becomes steeper than 35–40%, the logging helicopter usually follows longer, less direct flight paths to maintain an acceptable balance between travel speed and descent rate. Straight-line distance can substantially understate the actual yarding distance in this case, but predicting actual flight paths and flight distances is also difficult and requires experience and a sound understanding of the performance characteristics and capabilities of logging helicopters. In these situations, the forest engineer has the ability to influence yarding distance and flight-path slope through landing selection, and should involve the heli-logger early in the layout process to compare the advantages and disadvantages of the various alternatives. Horizontal distance can still be used as a measure of comparing yarding distances between the possible landing locations.

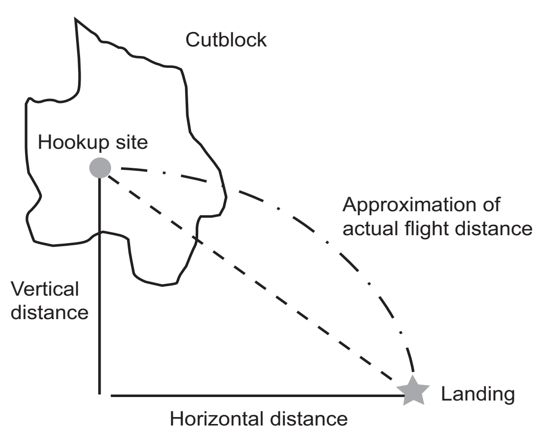


Figure A-1. Different ways of calculating yarding distance for a helicopter logging operation.

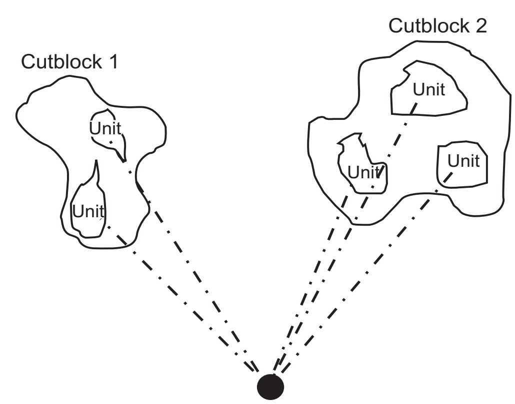
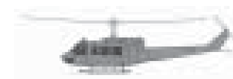
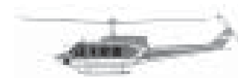
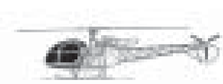
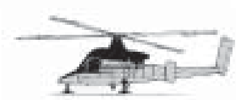
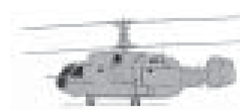
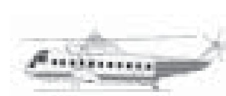


Figure A-2. Calculating effective average yarding distance for a project.

Appendix II

Specifications for helicopters commonly used for logging in B.C. [a]

Manufacturer	Model	Rated payload capacity (lb.)	Engines (no.)	Engine power [b] (kW)	Diameter main rotor (m)	Diameter tail rotor (m)	Diagram
Bell	204B	4 000	1	820	14.6	2.6	
Bell	205A	5 000	1	1 044	14.6	2.6	
Bell	212	5 000	2	671 (each)	14.7	2.6	
Bell	**214B**	**8 000**	**1**	**2185**	**15.2**	**2.6**	
Boeing	V-107 II	10 500	2	932 (each)	15.5	n/a	
Boeing	CH-234LR	28 000	2	3 039 (each)	18.3	n/a	
Sikorsky [c] Sikorsky [c]	S-64E S-64F	20 000 25 000	2 2	3 356 (each) 3 579 (each)	22.0 22.0	5.0 5.0	
Eurocopter	SA-315B Lama	2 500	1	640	11.0	1.9	
Kaman	K-1200	6 000	1	1342	14.7 (×2)	n/a	
Kamov	KA-32A	11 000	2	1645 (each)	15.9 (×2)	n/a	
Sikorsky	S-58T	5 000	2	700 (each)	17.1	2.9	
Sikorsky Sikorsky	S-61N S-61N Shortski	8 000 9 000	2 2	1 044 (each) 1 044 (each)	18.9 18.9	3.2 3.2	

[a] Helicopter capabilities will vary with flight conditions and installed options.
[b] Engine power at takeoff.
[c] Now manufactured by Erickson Air-Crane Inc.

Appendix III

Helicopter costs [a, b] ($/flight-hour)

	Bell 214B	Bell 206 Jet Ranger
OWNERSHIP COSTS		
Total purchase price (P) $	2 800 000	440 000
Expected life (Y) y	10	10
Expected life (H) h	24 910	12 000
Scheduled hours/year (h) = (H/Y) h	2 491	1 200
Net flight-hours/year (fh) h	1 892	962
Salvage value as % of P (s)	50	50
Interest rate (Int) %	9	9
Insurance rate (Ins) %	12	12
Salvage value (S) = ((P•s)/100) $	1 400 000	220 000
Average investment (AVI) = ((P+S)/2) $	2 100 000	330 000
Loss in resale value ((P-S)/(fh•Y)) $/flight-hour	74.00	22.87
Interest ((Int•AVI)/fh)/100 $/flight-hour	99.89	30.87
Insurance ((Ins•AVI)/fh)/100 $/flight-hour	133.19	41.16
Total ownership costs (OW) $/flight-hour	307.08	94.90
ANNUAL OPERATING COSTS		
No. of pilots required for the operation (pil)	2.5	1
Annual pilot base salary (PS) $/y	40 000	36 000
Annual flight hours/pilot (pilh) h/y	757	962
Pilot flight-hour rate (pil$) $/h	76.64	52.39
Annual pilot flight pay (PF) = (pilh•pil$) $/y	58 000	50 400
Wage benefit loading (WB) %	45	40
No. of co-pilots required for the operation (copil)	2.5	-
Annual co-pilot base salary (coPs) $/y	13 000	-
Annual flight hours/co-pilot (copilh) h/y	757	-
Co-pilot flight hour rate (copil$) &/h	24.91	-
Annual co-pilot flight pay (coPF)=(copilh•copil$) $/y	18 850	-
No. of engineers (eng)	2.5	-
Engineer salary (ES) $/y	75 000	-
Fuel consumption (F) L/flight-hour	697	113
Fuel (fc) $/L	0.55	0.55
Oil as a % of fuel (fp) %	3.0	3.0
Annual parts inventory (Inv) = % of P	2.5	2.5
Wages for the operation, including fringe benefits		
Pilots (((PS•pil)+(pil$•pilh•pil)/fh)•(1+(WB/100))) $/flight-hour	187.80	100.80
Engineer ((ES•(1+WB/100))•eng)/fh $/flight-hour	143.70	-
Co-pilot (((coPs•copil)+copil$•copilh•copil)/fh)•(1+WB/100)) $/flight-hour	61.04	-
Total wages (W) $/flight-hour	392.54	100.80
Fuel[c] (F•fc) $/flight-hour	383.35	62.15
Oil ((fp/100)•(F•fc)) $/flight-hour	11.50	1.86
Maintenance of non-dynamic and non-life limited parts $/flight-hour	513.22	150.48
Maintenance of dynamic and life limited parts $/flight-hour	260.23	77.52
Parts inventory ((Inv/100)•(P/fh)) $/flight-hour	37.00	11.43
Miscellaneous ($/flight-hour)	4.90	5.91
Total operating costs (OP) $/flight-hour	1 602.74	410.15
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/flight-hour	1 909.82	505.05

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

[b] Changes in the helicopter costing methodology have occurred since the last published FERIC report on helicopter logging (Dunham 2004). Changes are a result of acquiring new information regarding helicopter machine costs.

[c] Includes cost of transporting fuel to remote locations.

Appendix IV

Machine costs
($/scheduled machine hour (SMH), excluding labour) [a]

	Wheel loader 15–20 tonne class	Hydraulic log loader 25–30 tonne class
OWNERSHIP COSTS		
Total purchase price (P) $	325 000	450 000
Expected life (Y) y	5	5
Expected life (H) h	10 000	10 000
Scheduled hours/year (h)=(H/Y) smh	2 000	2 000
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	7	7
Insurance rate (Ins) %	3	3
Salvage value (S)=(P•s/100) $	97 500	135 000
Average investment (AVI)=((P+S)/2) $	211 250	292 500
Loss in resale value ((P-S)/H) $/h	22.75	31.50
Interest (((Int/100)•AVI)/h) $/h	7.39	10.24
Insurance (((Ins/100)•AVI)/h) $/h	3.17	4.39
Total ownership costs (OW) $/h	33.31	46.13
OPERATING COSTS		
Fuel consumption (F) L/h	30	30
Fuel (fc) $/L	0.56	0.56
Lube and oil as % of fuel (fp) %	10	10
Annual tire consumption (t) no.	2.0	0.0
Tire replacement (tc) $	3 000	-
Track and undercarriage replacement (Tc) $	-	20 000
Track and undercarriage life (Th)	-	5 400
Annual repair & maintenance (Rp) $	52 000	55 000
Fuel (F•fc) $/h	16.80	16.80
Lube and oil ((fp/100)•(F•fc)) $/h	1.68	1.68
Annual tire consumption ((t•tc)/h) $/h	3.00	-
Track and undercarriage (Tc/Th) $/h	-	3.70
Repair and maintenance (Rp/h) $/h	26.00	27.50
Total operating costs (OP) $/h	47.48	49.68
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) [a] $/h	80.79	95.81

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

Appendix V

Sensitivity analysis for helicopter hourly operating cost

This appendix demonstrates the potential magnitude of output variability produced from FERIC's costing framework and emphasizes the importance of using realistic and project-specific assumptions when developing cost estimates or evaluating harvesting bid proposals for an area.

A sensitivity analysis was performed to examine the effect of varying capital cost, yearly flight hours, maintenance costs, and unit fuel prices on the Bell 214B's hourly operating cost (Figure A-3). In this analysis, all but one of the parameters was kept constant, and that parameter was varied from +10 to -10% of the assumed value used for costing (see Appendix III) to determine its relative sensitivity to change. Figure A-3 suggests that changing the hourly maintenance cost has the greatest influence on the Bell 214B's hourly operating cost, increasing or decreasing the hourly cost by up to $77 per flight-hour. A change in unit fuel price has the next greatest impact, increasing or decreasing the hourly operating cost by +/-$38 per flight-hour, followed by changes to yearly flight hours (+$27/-$34 per flight-hour) and capital cost (+/-$30 per flight-hour).

A second analysis was performed (Figure A-4) to demonstrate the cumulative effect on the Bell 214B's hourly operating cost of reducing key cost parameters by 10% and increasing annual flight hours by 10% (Scenario 1). Conversely, the effect of increasing key cost parameters by 10% and reducing annual flight hours by 10% is shown in Scenario 2. This analysis indicates a cost variance of $305/flight-hour or $7/m^3 between Scenario 1 and 2.

Figure A-3. Single variable sensitivity analysis on the Bell 214B's hourly operating cost.

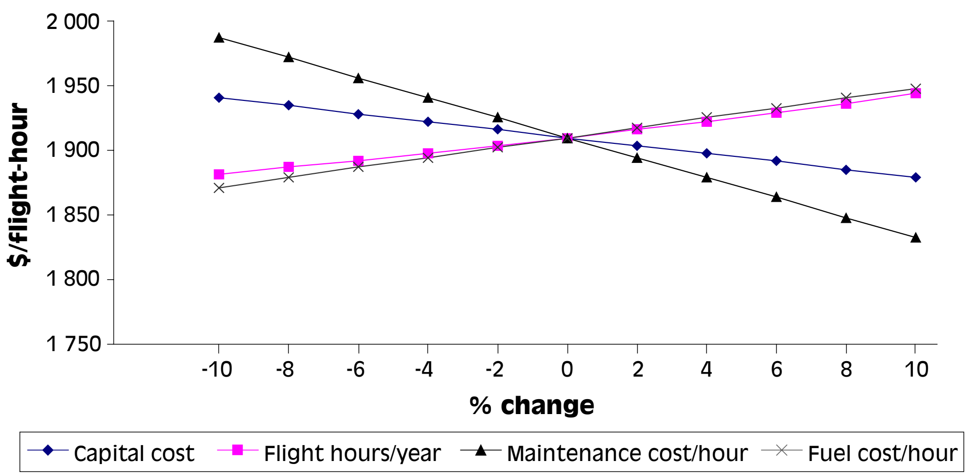


Figure A-4. Multiple variable sensitivity analysis on the Bell 214B's hourly operating cost.