PRODUCTIVITY AND PROFITABILITY OF GRAPPLE YARDING BUNCHED B.C. COASTAL SECOND-GROWTH TIMBER

by

A.J. MacDonald*

*Researcher
Harvesting Operations Group
Western Division

FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
#201-2112 West Broadway
Vancouver, B.C. V6K 2C8

October 1988

FERIC Special Report No. SR-54

This report is being released simultaneously by the Canadian Forestry Service as FRDA Report 048.

Keywords: Cable logging, Skyline, Grapple yarders, Productivity Costs, Downtime, Economic analysis, Second growth, Washington 118A yarding crane

ACKNOWLEDGEMENTS

The author wishes to thank the personnel of MacMillan Bloedel Limited, Northwest Bay Division, for their assistance during this project and for reviewing the manuscript. Special thanks go to Neil Marshall of FERIC for his assistance in data collection.

AUTHOR

Jack MacDonald graduated from the University of British Columbia Faculty of Forestry in 1976. He joined British Columbia Forest Products Limited and worked as a field engineer on Vancouver Island until joining FERIC in 1986. He is a Researcher in the Harvesting Operations Group.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

SUMMARY

As part of a series of studies on grapple-yarding techniques used in logging Coastal second-growth timber, the Canadian Forestry Service, under the Forest Resource Development Agreement (FRDA), contracted the Forest Engineering Research Institute of Canada (FERIC) to examine the productivity of grapple yarding mechanically felled and bunched timber. The study objectives were to examine the effect of bunching on yarder productivity and to determine the optimum bunch volume and marginal-log size. A Washington Model 118A yarding crane was monitored on a shift-level basis for five weeks and at a detailed-timing level for two weeks. The yarding crane averaged 62.1 m^3/PMH, or 414 m^3/8-h shift over the study block. The average cost was \$4.16/m^3. The study block was located approximately 10 km south of Parksville, B.C., and the stand was composed mainly of second-growth Douglas-fir.

During the two-week detailed-timing period, individual stems were marked for identification, the bunch volumes and turn volume calculated, and the yarding times for turns and bunches recorded. When a grapple with a 270-cm opening was used, productivity increased as bunch volume increased for all observed bunches. For a 200-cm grapple, productivity was highest with 7-m^3 bunches. Compared to a previous study (MacDonald 1987), yarding bunches instead of individual logs increased the average log count from 1.2 to 2.9 logs per turn and the average turn volume from 0.9 to 3.1 m^3.

The marginal-log volume was calculated using marginal economics analysis. The net value at roadside, and thus the marginal-log volume, was dependent on the handling methods used in subsequent phases such as processing and loading. When these costs were assumed to be piece-based, rather than volume-based, the net value at roadside was reduced for smaller stems and the change in marginal-log volume was not proportional to the change in number of stems in the turn. For Douglas-fir J-grade logs yarded individually, the marginal-log volume was 0.54 m^3, and when yarded in bunches of four stems, the marginal-log volume was 0.35 m^3. Based on these assumptions, 39% to 23% of the Douglas-fir J-grade logs were submarginal.

The average turn time increased to 2.15 min from 1.25 min observed in the previous study. Move and rig time occupied 16% of total time and most of this time was for moving the guylines. Also, each yarding cycle had a long fixed time to tighten the lines and engage the interlock.

INTRODUCTION

Yarding cranes have played an increasingly important role in Coastal harvesting operations over the last 15 years, however, one of their shortcomings has been their inability to yard multiple-piece turns consistently. It has been demonstrated that yarding-crane cycle times are not closely related to turn volume, and that yarding cranes often have capacity to yard more volume per turn (Peterson 1987a). These two factors are especially important when yarding second-growth timber where the average tree size is small. The opportunity exists to increase turn size by yarding several pieces per turn. Mechanically falling and bunching the timber is one possible method of increasing the average number of pieces per turn and, therefore, the yarding crane's payload. Feller-bunchers are common in the Interior of British Columbia, but until recently they have not been commonly used on the Coast.

The Canadian Forestry Service (CFS), under the Forest Resource Development Agreement (FRDA), contracted the Forest Engineering Research Institute of Canada (FERIC) to monitor the profitability of grapple yarding timber which had been mechanically felled and bunched. This report was prepared as a part of a series of studies on yarding techniques used in logging Coastal British Columbia second-growth timber. In the first study (MacDonald 1987), a yarding crane was monitored as it grapple yarded hand-felled second-growth timber. It was found that turn volume had the greatest influence on yarding profit, and that techniques should be developed to increase the turn volume and thereby increase yarding profitability. As used in this report, "yarding profitability" assumes that road construction, falling, ownership, and other costs are sunk costs, and have no bearing on decisions to be made in the subsequent phases. Other FERIC studies have also shown the effect of piece size, yarding distance, and falling techniques on grapple-yarding productivity (Peterson 1987b, 1987c, 1988). The objectives of this study were to examine the effect of bunching on yarding productivity and to determine the optimum bunch volume and marginal-log size.

Data presented here were collected from a study area located near Parksville, B.C., on the east coast of Vancouver Island, in MacMillan Bloedel Limited's Northwest Bay Division. It was logged in February and March 1988 by company crews using a Washington 118A yarding crane. The stand consisted mainly of second-growth Douglas-fir, with minor amounts of pine, cedar, and other species.

STUDY APPROACH AND PROCEDURES

The study involved two levels of timing: shift-level timing and detailed timing.

To collect shift-level timing data, a Model DSR Servis Recorder was mounted on the yarding crane, and a chart was produced for each shift showing productive and non-productive times. The operators identified each delay over 10-min duration on the chart, provided an explanation of the cause of each delay, and recorded daily piece counts. Volume information was obtained from the company's production records.

Data were collected relating to both logs in bunches and logs in turns. For this study, bunches are defined as the groups of logs made by the feller-buncher and turns are the groups of logs held at one time by the yarding grapple.

The study was carried out over five weeks. Shift-level data were collected for 24 production shifts and, during two weeks of this period, more detailed information was collected on 1344 yarding turns. The yarding crane operated on the block for one week before the Servis Recorder was installed.

For the detailed-timing study, cycle times were measured using electronic stopwatches. Minor delays (less than 10 min) were included in the machine cycle, and longer delays were excluded. Log-butt diameters were measured prior to yarding, and 10-cm diameter classes were marked on the logs to help determine average turn volumes. Yarding distances, number of yarded logs, and number of missed logs per turn were recorded. The angle of each bunch in relation to the yarding road, measured in 30-degree classes, was estimated. Turns were classified by type, i.e. whether all target logs were hooked or some were missed, whether it was the first or subsequent turn from a particular bunch, and whether a log slipped from the grapple or was broken during yarding.

To help estimate turn volume, sample logs were scaled by a licenced scaler according to B.C. Ministry of Forests and Lands' standards. Logs were scaled either before or after yarding, depending on crew scheduling. Average log volumes were calculated by butt-diameter classes and applied to the log counts to calculate volumes per turn.

The costs included in this report are based on current IWA wage rates and estimates of machine costs derived by FERIC from information supplied by equipment and supplies distributors. They are not the actual costs incurred by the cooperating company, and costs such as supervision, overhead, and crew and machine transportation are not included. Interest costs are calculated for information (Appendix I), but are not included in the production costs within the report.

SITE AND SYSTEM DESCRIPTION

The study site was located on the east coast of Vancouver Island, approximately 10 km south of Parksville, B.C. The stand was established in approximately 1910. Table 1 shows a description of the site and Table 2 shows the species and grade distribution derived from the company production records. Arbutus trees were left at the roadside and were not scaled. The log grades shown are B.C. Ministry of Forests and Lands' statutory grades; common-usage log-grade definitions are included for information.

The logging area was generally flat and uniform with boundaries determined by surrounding roads rather than by terrain features. With the exception of some small swampy areas, the soil was well drained and access for the feller-buncher or mobile backspar was not restricted by soil-bearing capacity.

TABLE 1. Site Description

Cutting area	
- Study area	25.2 ha
- Total setting	29.0 ha
Average slope	5%
Terrain	Flat
Exposed rock	None
Underbrush	Moderate
Obstacles	Nil
Net volume/ha, as produced	382 m^3 /ha
Piece size from scaled stems	
- Range	0.07 - 6.62 m^3
- Average	1.12 m^3

TABLE 2. Species and Grade Distribution Within the Study Block[a]

Species	% of study block	Grade %[b]							
		C	H	I	J	X	Y	No grade	Total
Douglas-fir	97	3	22	14	55	5	1	-	100
Cedar	1	-	-	20	65	9	6	-	100
Hemlock	<1	-	-	15	71	14	-	-	100
Balsam	<1	-	-	37	46	16	1	-	100
Spruce	<1	-	-	-	58	30	12	-	100
Pine	2	-	7	3	64	23	3	-	100
Alder	<1	-	-	-	-	-	52	48	100
Total	100	3	21	14	55	6	1	0	100

[a] Arbutus stems which had been yarded were neither loaded nor included in production records.

[b] Grade definitions:

C - Peeler
H - Sawlog
I - Sawlog
J - Small sawlog
X - Low-grade sawlog
Y - Pulp

Trees were mechanically felled by a contractor using a John Deere 793C feller-buncher with a Rotosaw falling head. Stems were left tree-length for roadside processing except those over 60-cm butt diameter which were hand-felled and bucked into log lengths after the smaller trees had been felled. Company personnel marked internal boundary lines prior to falling to help the feller-buncher operator fall the trees with butts facing the truck road. It was planned that the bunches should lie at approximately 45 degrees to the truck road to facilitate yarding, but study results showed that the log angle varied throughout the setting.

The number of stems in each bunch depended on tree size and distribution, and varied throughout the setting. In Week 1 of the two-week detailed-timing study, the average tree size was larger (Figure A), many trees were hand-felled, and the highest stem count per bunch was about 10 stems. In Week 2, the average tree size was smaller (Figure B), and bunches with up to 23 stems were observed.

FIGURE A. Large-Log Bunch: Week 1.

FIGURE B. Small-Log Bunch: Week 2.

The feller-buncher cleared a path for the backspar through the felled timber by piling stems parallel to the haul road on either side of its path. No attempt was made to pile them into bunches. When logging was in progress, the mobile backspar moved these logs once again from their original positions to facilitate yarding. FERIC observed that many turns from these piles were smaller than normal because of difficulty in hooking multiple pieces.

Yarding was carried out with a 1978 Washington 118A yarding crane (Figure C) with a mobile backspar. The Washington 118A is a modified Washington 118 (Phillips and Sauder 1978) in which the hydraulic interlock has been replaced with a mechanical interlock. The current equivalent is the Washington 188 (Appendix II). Normal shift length was eight hours per day for five days per week. During most of the detailed-timing period, a Hitachi UH 171 (Figure D) was used for the backspar. However, during the latter part of Week 2 and the remainder of the shift-level study, a Caterpillar D8K bulldozer was used.

FIGURE C. Washington 118A Yarding Crane.

FIGURE D. Hitachi UH 171 Backspar.

The yarding crew consisted of a yarding engineer (Operator 1), a hooktender, a part-time landingman, and a trainee operator (Operator 2). The trainee operator was the sole operator for approximately 40% of the time, the regular operator for approximately 20%, and the two shared duties for approximately 40% of the study period. The regular operator had 10 years' experience on the Washington 118A, and FERIC considered him to be skilled and efficient. Although the second operator had some previous experience on the Washington 118A, he was considered to be a trainee operator during the study. His times have been included in the shift-level study, but excluded from some of the more detailed analyses. The hooktender aided with guyline moves as well as spotting logs and moving the backspar. The landingman was on-site for approximately three-quarters of the time, and he prepared guyline stumps and assisted with guyline moves.

Stems were yarded to roadside and piled in windrows (Figure E) for subsequent processing. Windrows were up to 4 m high depending on stand density, stem size, and yarding distance. The stems were delimbed and cut to length with a Hahn Harvester which was fed by an American 7220C cable log loader. Logs were loaded onto off-highway log trucks with a Caterpillar 225 hydraulic log loader (Figure F). Haul distance was approximately 2 km to the sortyard at Northwest Bay. During processing, logs were sorted into sawlogs and pulpwood. The sawlogs were further sorted and scaled at the sortyard. The pulpwood was weigh-scaled and then sent directly to a chipping facility at the sortyard.

FIGURE E. Windrow of Yarded Stems.

FIGURE F. Roadside Processing Equipment.

RESULTS AND DISCUSSION

1. Setting Layout

In addition to the existing roads surrounding the area, new roads were constructed inside the logging area at approximately 250 to 300 m spacing (Figure G). In one area during Week 1, the original backspar trail was positioned below a small ridge and its location had to be changed. Since the slope averaged approximately 5%, deflection was reduced at longer yarding distances (150-180 m) and the operators had to maintain high tension on the lines to keep the grapple clear of the ground. This made it more difficult to control the grapple during hookup. Minor slope variations (less than 5%) further reduced deflection in some places. The flat ground also made it difficult to raise heavy turns clear of the stumps, resulting in hangups and increased inhaul times. However, these were minor difficulties, and the overall setting layout was very good.

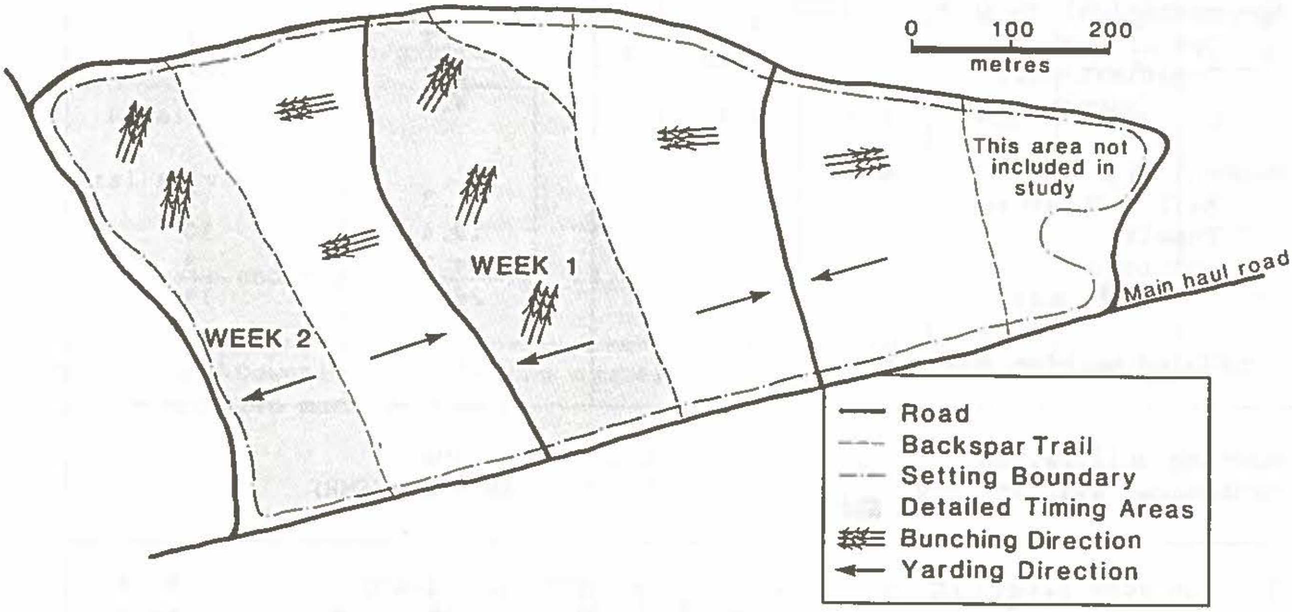


FIGURE G. Setting Layout.

2. Shift Level Results

A Servis recorder, mounted on the yarding crane for 24 production shifts, showed that the average shift length was 7.8 hours (Table 3) and the actual yarding time averaged 5.2 hours per shift. Total production was 8778 trees with an average volume of 1.10 m^3/tree. The average production was 376 trees, or 414 m^3, per 8-hour shift. If the arbutus logs had been included in the total volume, these production rates would have increased slightly. Total machine time was about 187 hours. At an estimated cost of $211.07 per hour for yarder, backspar, and crew, average yarding cost was $4.08/$m^3$.

Machine utilization was 83% during the study period. Yarding time represented 67% of the total time, moving and rigging occupied 16%, while non-mechanical delays (3%) and mechanical delays (14%) made up the remaining time. Further information on time distribution is in Appendix III and further discussion on moving time is in the detailed-timing section of this report.

TABLE 3. Shift-Level Time Distribution

Shifts with production	Hours	Percent
Productive machine hours (PMH)		
Yarding time	124.6	67
Other function	30.8	16
Subtotal	155.4	83
Non-mechanical delay hours (NDH)		
Operational	1.7	1
Organizational	3.0	2
Subtotal	4.7	3
Mechanical delay hours (MDH)		
Wait mechanical	2.3	1
Repairs	19.4	10
Service	4.9	3
Subtotal	26.6	14
Scheduled machine hours (SMH)	186.7	100

Machine utilization	83.3%	(PMH/SMH)
Mechanical availability	85.8%	((SMH-MDH)/SMH)

Average stem size(m^3/tree)	1.10	Production (stems)	8778
Production (m^3)	9620	Production/PMH (m^3/h)	62.1
Shifts with production	24	Production/PMH (stems/PMH)	56.5
Average shift length (h)	7.78	Production/8 hrs (m^3)	414

The mechanical downtime ratio (MDR), defined as the number of repair or service hours required for 100 productive machine hours, was 20.1 during this study (Table 4). In-shift repairs totalled 24.3 hours. Some lengthy in-shift repairs involved respooling the cables and repairing the grapple (8.9 h), repairing the air controls on the winch interlock (6.6 h), and adjusting the winch brakes (2.1 h). Out-of-shift repairs consisted of repairing the guyline fairlead (2 h) and track frame (5 h). The crew felt that the Washington 118A's undercarriage was too light for the yarder and was the source of much downtime.

3. Detailed-Timing Results

The detailed-timing study was completed in two weeks, although five weeks were required to complete the entire study. The operating conditions varied slightly from the first to the second week of the detailed-timing period. During Week 1, the average yarding distance was longer and the trees were larger; during Week 2, Operator 2 was working elsewhere. A summary of the detailed-timing results is shown in Table 5.

TABLE 4. Summary of Maintenance

	In-Shift		Out-of-Shift		Total	
	Hour	MDR[a]	Hour	MDR[a]	Hour	MDR[a]
Repairs to carrier	0.6	0.4	5.0	3.2	5.6	3.6
Repairs to winch/lines/grapple	18.8	12.1	2.0	1.3	20.8	13.4
Repair subtotal	19.4	12.5	7.0	4.5	26.4	17.0
General service	4.9	3.1	0.0	0.0	4.9	3.1
Total repair and service	24.3	15.6	7.0	4.5	31.3	20.1

[a] Mechanical Downtime Ratio - the number of repairs or service hours per 100 productive machine hours.

TABLE 5. Summary of Detailed-Timing Period

	Week 1			Week 2	Week 1 & 2
	Oper. 1[a]	Oper. 2[b]	Both	Oper. 1[a]	Combined
Avg yarding distance (m)	75	89	82	72	77
Max. yarding distance (m)	180	180	180	140	180
No. of turns	393	386	779	565	1344
No. of pieces	825	766	1591	2339	3930
Productive time (h)	12.8	16.3	29.1	19.2	48.3
Pieces/turn	2.1	2.0	2.0	4.1	2.9
Avg butt diameter (cm)	35.2	38.8	36.9	26.4	30.7
Volume yarded (m^3)	1144	1235	2379	1797	4176
Avg volume/turn (m^3)	2.9	3.2	3.1	3.2	3.1
Turns/PMH	30.7	23.7	26.8	29.4	27.8
Pieces/PMH	64.5	47.0	54.7	121.8	81.4
Volume/PMH	89.4	75.8	81.8	93.6	86.5

[a] Experienced operator.
[b] Trainee operator.

The productive time during the detailed-timing period was divided into work-cycle elements (Appendix IV), and the results are shown in Table 6. The portion of time spent in net yarding ranged from 59% to 67%, and averaged 63% of productive time. A further 26% to 33% of time was spent moving the yarding crane, backspar, or guylines, while 4% to 11% of productive time was spent in minor delays. The average turn time, including moves and minor delays, ranged from 1.95 to 2.54 min per turn, and averaged 2.16 min for the 1344 turns which were timed.

Both operators were timed during Week 1, and the benefit of experience is seen in the shorter cycle times for Operator 1. The difference is most apparent in hook-up time, as might be expected, but differences also occurred in outhaul and inhaul times. The Washington 118A requires a specific sequence of actions to tighten the lines and engage the interlock, and the more experienced operator was able to perform those actions more quickly than the trainee operator.

The move and rig times for the two operators in Week 1 are not directly comparable since the operators generally traded positions during yarder moves, and times were arbitrarily assigned to one of the operators. The move and rig time for Week 1 was shorter than for Week 2 for two reasons: the yarding distance was longer in Week 1 and moving time represented a smaller portion of total time, and, for one day in Week 1, the yarding crane remained stationary and the backspar moved in an arc to cover the yarding area.

TABLE 6. Summary of Productive-Time Elements

	Percent					Min/Turn				
	Week 1			Week 2	Weeks 1 & 2	Week 1			Week 2	Weeks 1 & 2
	Op. 1[a]	Op. 2[b]	Both	Op. 1[a]	Combined	Op. 1[a]	Op. 2[b]	Both	Op. 1[a]	Combined
Net yarding time										
Outhaul	18	17	18	15	17	0.35	0.43	0.40	0.31	0.37
Hookup	16	20	18	18	18	0.31	0.51	0.40	0.37	0.39
Inhaul	17	19	19	16	17	0.33	0.48	0.43	0.33	0.37
Unhook	6	6	5	6	6	0.12	0.15	0.11	0.12	0.13
Deck	6	5	6	4	5	0.12	0.13	0.13	0.08	0.11
Subtotal	63	67	66	59	63	1.23	1.70	1.48	1.21	1.37
Move-and-rig time										
Move logs	5	2	3	3	3	0.10	0.05	0.07	0.06	0.06
Move backspar	8	5	6	7	7	0.16	0.13	0.13	0.14	0.15
Move yarder	6	3	4	1	3	0.11	0.08	0.09	0.02	0.06
Move guylines	7	19	14	22	17	0.14	0.48	0.31	0.45	0.37
Subtotal	26	29	27	33	30	0.51	0.74	0.60	0.67	0.64
Minor delay	11	4	7	8	7	0.21	0.10	0.16	0.16	0.15
Productive time	100	100	100	100	100	1.95	2.54	2.24	2.04	2.16

[a] Experienced operator.
[b] Trainee operator.

Overall, move and rig time represented 30% of productive time, and move guylines time accounted for most of that time. Time per guyline move averaged 23 min and 18 min for Weeks 1 and 2 respectively. The Washington 118A had two guylines side-by-side in one guyline block, and a third in another block. The single guyline could be moved independently of the others, but the double guylines had to be moved together to keep their alignment correct. This doubled the amount of work and increased move times. Altering the blocks to allow each guyline to be moved independently would reduce move times.

Minor delays occupied from 4 to 11% of productive time (Table 7). Of these, mechanical delays were the most common, followed by talking on the radio to the hooktender, waiting for the hooktender to move into position to spot logs, and waiting for the hooktender to check the yarding road. Lengthy miscellaneous delays in Week 2 included allowing traffic to pass the yarding crane.

TABLE 7. Minor Delays During Productive Time

Minor Delays	Percent of Delays	
	Week 1	Week 2
Mechanical	32	25
Clear lines	11	6
Wait for traffic or workers	10	7
Check yarding road	9	8
Talk on radio	8	16
Visitors to work site	7	3
Miscellaneous	6	23
Change operator	5	-
Start backspar	5	6
Unknown	5	4
Personal	2	2
Total	100	100

4. <u>Turn Size and Bunch Volume</u>

Table 5 shows the log counts averaged 2.0 and 4.1 logs per turn for Weeks 1 and 2 respectively, and further detail is provided in Figure H. For both weeks, turns with only one log were most common, although the proportion of turns with more than four logs was greater in Week 2. This resulted in its higher average number of logs per turn.

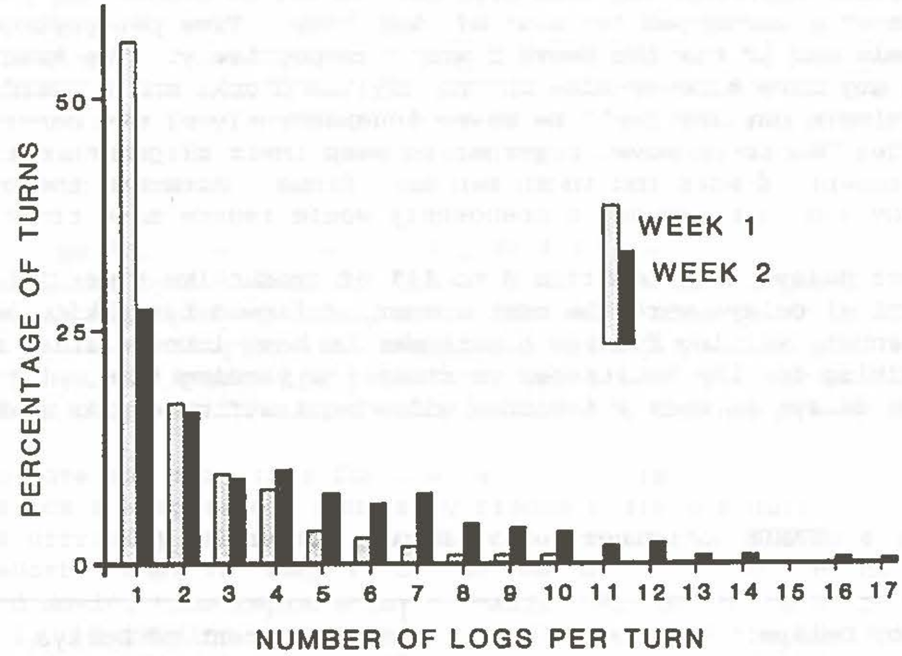


FIGURE H. Number of Logs Per Turn: Weeks 1 and 2.

Turn volumes were calculated by multiplying the log count in each butt-diameter class in the turn by the average volume for the butt-diameter class (Appendix V). For this analysis, arbutus logs were included in the log count and their volumes were calculated from the log volume of the same diameter class conifer log. Figure I shows the percentage of turns in each volume class.

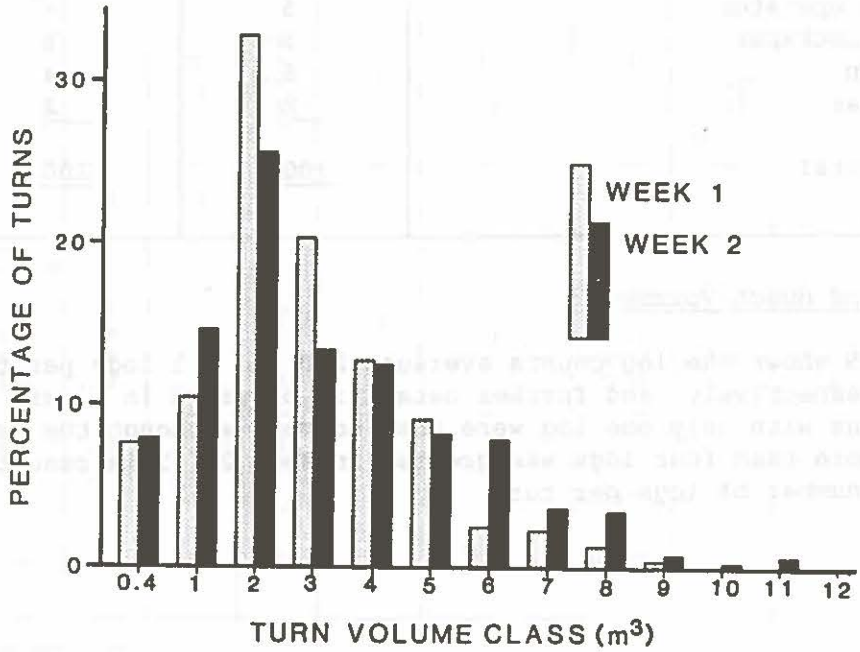


FIGURE I. Turn Volumes: Weeks 1 and 2.

Both weeks averaged 3.2 m³ per turn and had most turns in the 2-m³ class, but Week 2 had more variation in turn volume. The higher proportion of 1-m³ turns for Week 2 was offset by the higher proportion of 6-, 7-, and 8-m³ turns. Without these large turns, the average turn volume would have been much smaller.

When an entire bunch is yarded with one turn, productivity should increase as bunch volume increases, however, FERIC observed many turns where the yarding crane failed to hook the entire bunch on the first turn. Therefore, the data were examined to determine the effect of bunch volume and number of turns per bunch on productivity. Three different grapples were used during the study, and they will be discussed in detail later. The largest grapple was selected for bunch-volume analysis.

The volumes of the original bunches were calculated and stratified into 1-m³ classes. A distribution of bunch volumes was plotted showing the percentage of each volume class yarded in one, two, or more turns (Figure J). The proportion of multiple-turn bunches increased as bunch volume increased, with a large increase at approximately 7 m³ . Only a small percentage of bunches over 8 m³ were yarded in one turn.

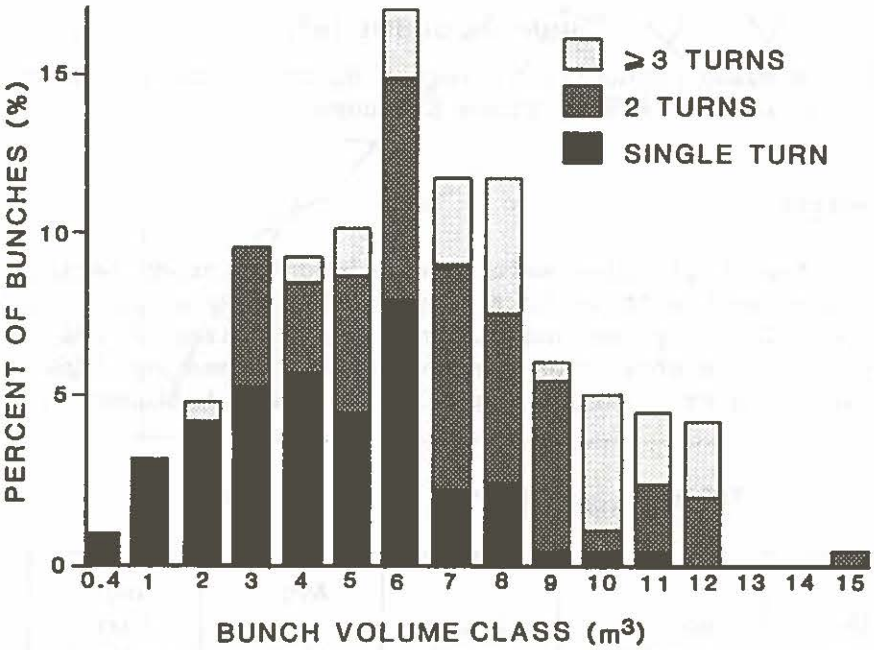


FIGURE J. Distribution of Bunch Volume.

The total yarding time, excluding minor delays and moving time, was calculated for each bunch, and the average gross productivity (m³ /h) was calculated for each bunch-volume class (Figure K). The standard deviation of gross productivity is also shown. Productivity increased as bunch volume increased, although the trend for bunches larger than 10 m³ was not clear. There did not appear to be an optimum bunch size for this grapple. Since no delays were included in the calculations, the productivity levels shown in Figure K cannot be maintained over a typical operating period.

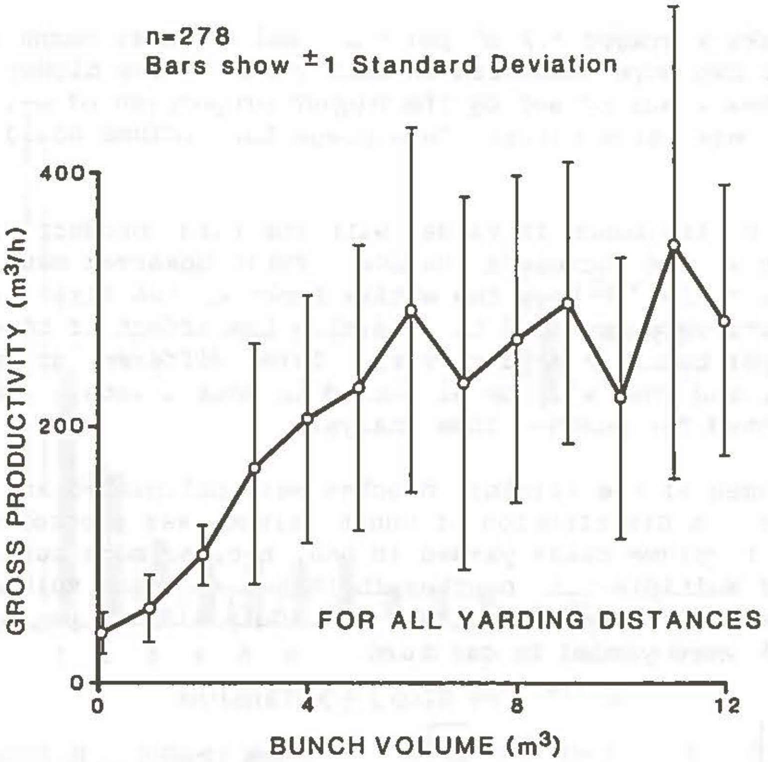


FIGURE K. Yarding Productivity Versus Bunch Volume for Grapple 1: Delay and Moving Times Excluded.

5. Grapple Comparison

Three different grapples were used during the study period; the company wanted to experiment with various grapples before purchasing one for a new yarding crane. The grapples had maximum opening sizes of 270, 230, and 200 cm respectively. Table 8 shows the average bunch volumes and hook-up times for each of the three grapples. Single-log turns were not included in the summary.

TABLE 8. Summary of Grapples Used[a]

Grapple number	Maximum opening (cm)	No. of bunches	No. of turns	Avg hook-up time (min)	Avg turn volume (m^3)	Avg bunch volume (m^3)
1	270	278	430	0.37	3.6	5.7
2	230	22	40	0.35	3.7	6.7
3	200	92	137	0.35	2.8	4.2

[a] Trainee operator excluded.

Note that Grapple 2 yarded only 22 bunches. The operators did not like the grapple's balance, and it was quickly replaced. Because of the small sample size, it was not included in further analysis.

Figure L shows the average turn volume versus bunch volume for all bunches yarded by Grapples 1 and 3, and for multiple-turn bunches yarded by Grapple 1. Because some bunches were yarded with only one turn, a difference occurs between the two curves shown for Grapple 1 (approximately 0.5 to 1.0 m^3 /turn). The turn volumes for all bunches for both grapples were about equal up to 7-m^3 bunch volume, after which the turn volume for Grapple 3 declined.

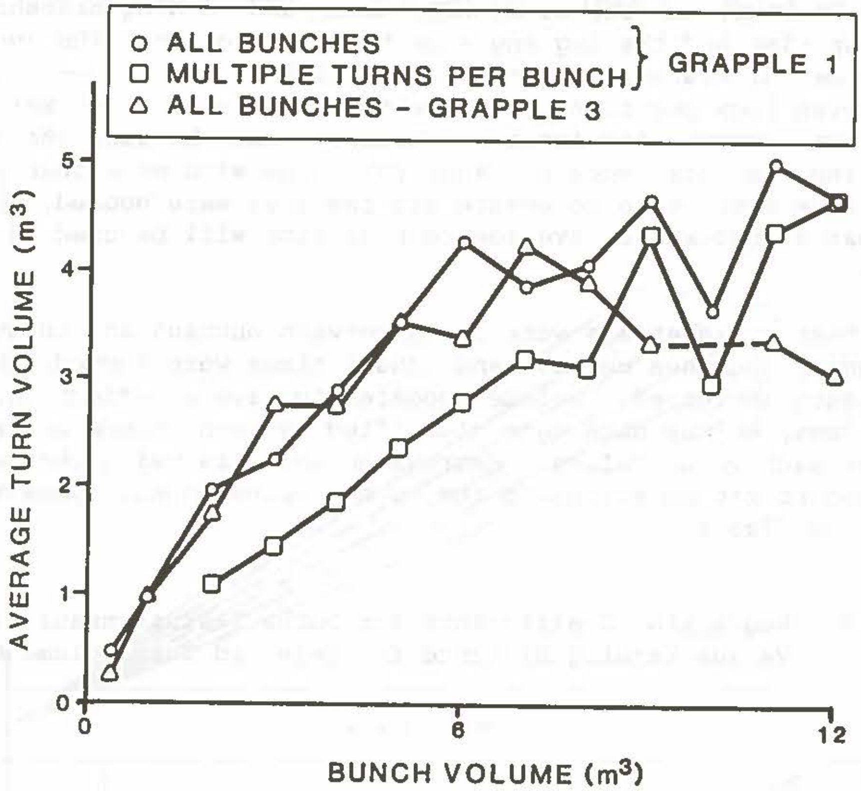


FIGURE L. Average Turn Volume Versus Bunch Volume.

The difference in average turn volumes between Grapples 1 and 3 was caused by differences in average bunch volume. Grapple 1 had larger bunches and its average turn volume was larger. Grapple 3 was used when the bunch volume was smaller and its average turn volume was smaller. The smaller grapple's turn volume declined for larger bunches, which showed that its optimum bunch volume was 7 m^3 . The average turn volume for Grapple 1 continued to increase as bunch volume increased above 7 m^3 , which showed it had not yet reached its optimum bunch volume.

Felling practices were not monitored during this study, and it is not known how the operator determined individual bunch volumes, however, it appeared that the operator placed as many stems as possible in each bunch. In a similar stand, it may not be practical to build bigger bunches without decreasing feller-buncher productivity. Thus, if further study showed that yarding productivity could be increased with even larger bunches, the gains might be made only at the expense of decreased feller-buncher productivity.

The operators preferred Grapple 1. They felt it was the more productive grapple, and it was used for the remainder of the study block. For simplicity, the following analysis will use only those turns yarded with Grapple 1.

6. Work-Cycle Elements Regression Analysis

The various cycle elements were examined to determine if they were correlated with yarding distance or other parameters. No correlations were found between hook-up, unhook, or decking times and yarding distance, or between hook-up time and the log angle or the turn volume. The average hook-up time showed some correlation with the number of logs per turn--it was minimized for five to seven logs per turn. Turns with fewer logs, which were often the second turn from a bunch, had increased hook-up times because the logs had been disturbed during the first hookup. And, for turns with more than seven logs, the operator took extra time to ensure all the logs were hooked. However, the correlation was slight and an average hook-up time will be used in the model for turn time.

The best correlations were found between outhaul and inhaul times and yarding distance, and when outhaul and inhaul times were summed, the correlation coefficients increased. Volume appeared to have an effect on outhaul-plus-inhaul times, so the data were classified by turn volume and analyzed separately for each volume class. Regression analysis using the least-squares method was used to fit equations to the outhaul-plus-inhaul times versus yarding distance (Table 9).

TABLE 9. Regression Coefficients for Outhaul-Plus-Inhaul Times Versus Yarding Distance for Selected Turn-Volume Classes[a]

Weeks 1 & 2				
Turn volume (m^3)	r^2	Constant	Slope	n
0 - 2	0.60	0.25	0.00501	267
2 - 4	0.70	0.24	0.00561	334
4 - 6	0.77	0.19	0.00662	150
6 - 8	0.57	0.29	0.00626	64
8 - 10	0.64	0.32	0.00533	19
10 - 12	0.93	0.10	0.00953	5

[a] Trainee operator excluded.

The regression coefficients were examined to determine if they had some pattern. No clear pattern was found for the regression constants and an average was used for all volume classes. However, the regression slopes generally increased as turn volumes increased and an equation was derived showing the regression slope as a function of turn volume. The final equation for outhaul-plus-inhaul is:

$$\text{Outhaul} + \text{Inhaul} = 0.25 + d * (0.00455 + 0.00030 * v)$$

where: Time is predicted in minutes
Distance (d) is measured in metres
Turn volume (v) is measured in cubic metres

Figure M shows the predicted outhaul-plus-inhaul times for selected turn volumes.

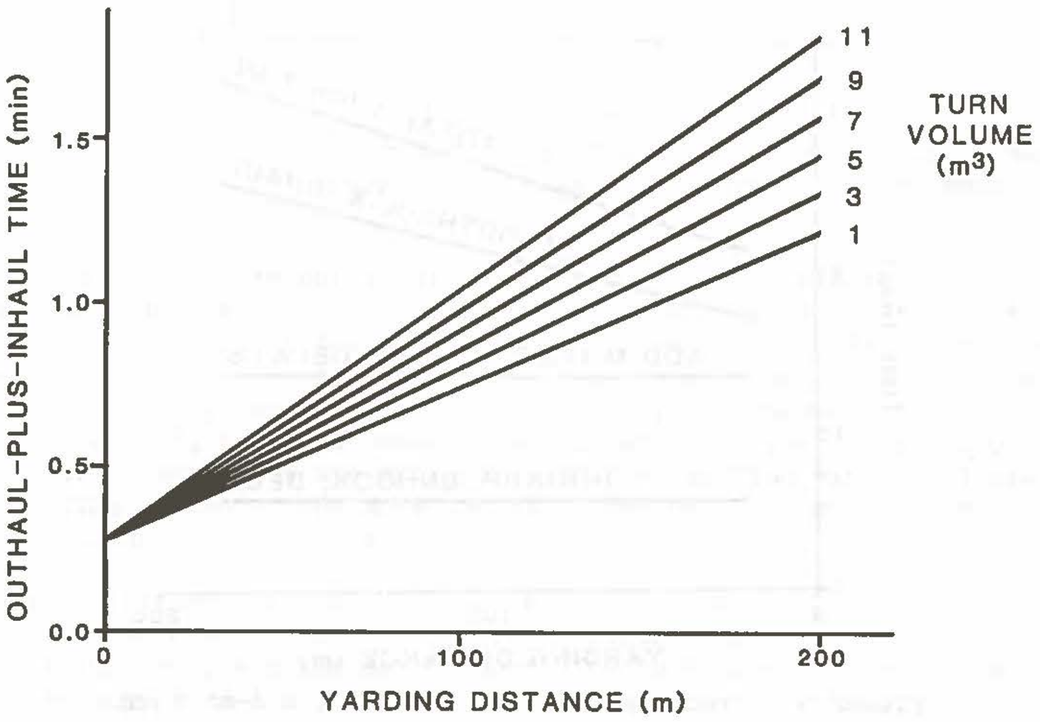


FIGURE M. Predicted Outhaul-Plus-Inhaul Times: Operator 1.

7. <u>Model of Yarding Times</u>

The shift-level and detailed-timing results were combined to make a model of yarding time for various distances and bunch volumes (Table 10). The moving and minor delay times were included for both operators, and the other element times were included for Operator 1. Figure N shows the predicted element times for the average turn volume during the detailed-timing period.

TABLE 10. Predicted Yarding-Cycle Times[a]

Outhaul and inhaul	0.25 + (0.00455 + 0.00030 v) d
Hookup, unhook, and deck	0.56
Yarding time	0.81 + (0.00455 + 0.00030 v) d
Moves	0.64
Minor delays	0.15
Total turn time	1.60 + (0.00455 + 0.00030 v) d

where: Yarding distance (d) is measured in metres
Turn volume (v) is measured in cubic metres
Time is predicted in minutes

[a] Trainee operator excluded from yarding time.

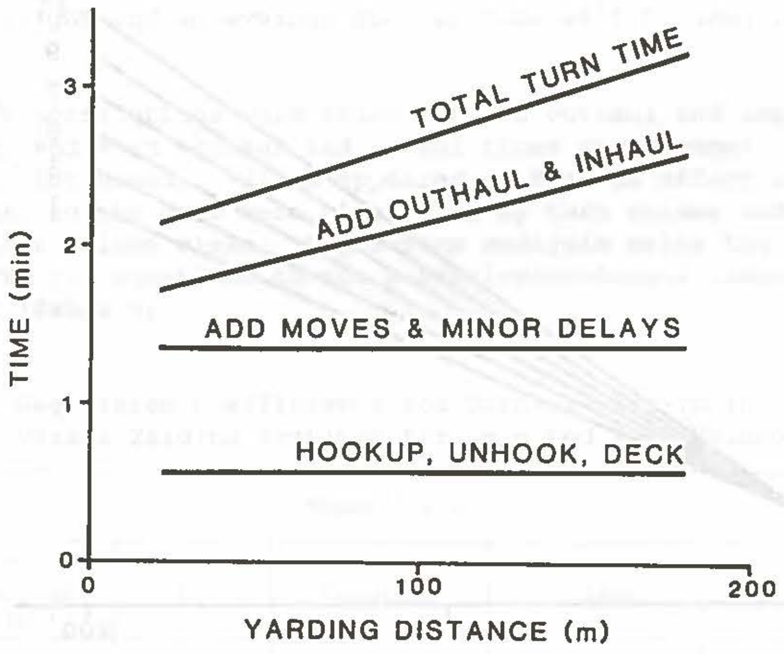


FIGURE N. Predicted Element Times for a 3-m^3 Turn.

Using the model in Table 10, the machine utilization from Table 3, and the turn volumes for all bunches for Grapple 1 in Figure L, the turn times were calculated for various bunch volumes and yarding distances, and the net productivity per hour was calculated (Figure O). Larger bunches resulted in larger turn volumes, and larger turns affected productivity in two ways: 1) more volume was delivered to roadside with each turn, and 2) cycle times were slightly increased. Figure O clearly shows that the negative influence of longer turn times was outweighed by the increase in volume delivered to the roadside.

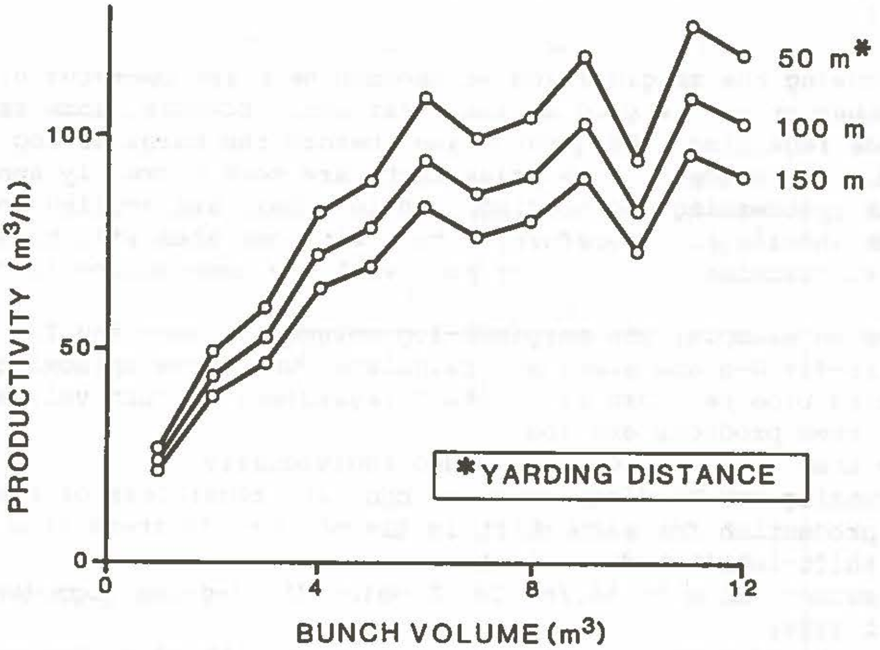


FIGURE O. Predicted Yarding Productivity Versus Bunch Volume For Grapple 1: Delay and Moving Times Included.

The three different yarding distances shown in Figure O are examples of the actual distance to the bunch, not the maximum yarding distance for the setting. The productivity for a setting where the boundary is 150 m from the roadside, for example, is the weighted average of all three curves; it would be incorrect to use only the curve for 150 m. Also, the curves include the average move and rig times for Weeks 1 and 2, when the average yarding distance was 77 m. If these curves are applied to another setting with a different average yarding distance, the move and rig times per turn must be adjusted to reflect the changing conditions.

The difference between Figures K and O is caused by delays and moving times. The gross productivity in Figure K ranges from 150-250 m^3/h for average-size bunches, and the net productivity in Figure O ranges from 50-80 m^3/h for the same size bunches.

8. Marginal-Log Analysis

The marginal-log volume is defined as the volume of a log for which the variable yarding cost is equal to the net value at roadside. The variable yarding cost excludes any sunk costs such as road construction, falling, and ownership costs, and the net value at roadside is the sales value of the log less any further costs which must be incurred. If yarding standards are determined according to marginal-log analysis, net income will be maximized regardless of the volume extracted from the setting because logs above the margin add to profit while logs below the margin reduce the profit. The first study in this series (MacDonald 1987) showed that when yarding hand-felled timber, the marginal-log volume was determined by species, grade, and turn volume with turn volume having the greatest effect. In that study, the marginal-log volume for J-grade Douglas-fir logs was 0.59 m^3, and 24-46% of the J-grade logs were submarginal.

Knowing the marginal-log volume can help the operator or hooktender to decide whether or not to yard a particular log. However, some assumptions must be made regarding subsequent phases before the marginal-log volume can be determined. For example, some phase costs are more correctly applied on a per-piece basis (processing and loading), while others are applied on a per-cubic-metre basis (hauling). Therefore, a turn with one stem will have a different net value at roadside than another turn with the same volume in four stems.

As an example, the marginal-log volumes of one- and four-stem turns with Douglas-fir J-grade stems are calculated under the following assumptions:

- yarding time per turn is constant regardless of turn volume
- each stem produces one log
- each stem is processed and loaded individually
- processing and loading costs are constant regardless of stem size
- the production for each shift is 414 m^3, or 376 stems (the average during the shift-level study period)
- the market value is $41/$m^3$ for Douglas-fir J-grade logs (Vancouver, B.C., April 1988)
- the combined stumpage and sales expense is 15% of market value.

The net value at roadside, which depends on stem size, must be determined before the marginal-log value can be calculated, therefore, initial stem-size estimates must be made. For 0.54- and 0.35-m^3 stems, the net values at roadside are $12.19/$m^3$ and $4.73/$m^3$ respectively (Table 11).

The time/turn was the average turn time during the detailed-timing period, adjusted for utilization. The system variable cost was $153.40/h and the average cost per turn was $6.62. The marginal-turn volume is calculated by dividing the cost per turn by the net value at roadside, and the marginal-turn volume is divided by the number of logs per turn to calculate the marginal-log volume. Since the calculated volumes in Table 11 equal the initial estimates, they are the correct volumes. If they had been different, new tree-volume estimates would be made, and the process repeated.

Appendix V shows the percentage of Douglas-fir J-grade stems which were smaller than selected volume-class boundaries for the scaled stems. By interpolating this table, it is seen that 23% of the Douglas-fir J-grade stems were smaller than 0.35 m^3, or submarginal if yarded in bunches of four and 39% were smaller than 0.54 m^3, or submarginal if yarded individually.

The marginal volume decreased as stems were bunched. However, it did not decrease in the same ratio as the increase in number of stems, i.e. yarding four times the number of stems did not reduce the marginal volume by three-fourths because of piece-based costs such as processing and loading. FERIC did not monitor those phases during this study, so processing and loading rates were assumed to be equal to the yarding crane's production. If the production rate in each phase was different, the net value at roadside would change, and the marginal-log volume would change. Further calculations based on assumptions would be pointless, however, these calculations illustrate that bunching reduces the marginal-log volume and that yarding profitability is influenced by other phases. The other phases must be designed to handle stems on a volume basis, rather than a piece basis, to maximize yarding profitability.

TABLE 11. Example of Marginal-Log Volume Calculations: Douglas-Fir J-Grade Logs

	$/Shift	$/Piece	One-stem turn 0.54 m³ / stem $/m³	Four-stem turn 0.35 m³ / stem $/m³
Calculation of net value at roadside				
Cost				
Processing	1500	3.99	7.38	11.45
Loading	1250	3.32	6.15	9.54
Hauling	880		2.13	2.13
Sorting and booming			6.00	6.00
Towing			1.00	1.00
Stumpage and sales expense			6.15	6.15
Total cost			28.81	36.27
Market value			41.00	41.00
Net value at roadside			12.19	4.73
Calculation of marginal-log volume				
Variable yarding cost ($/h)			$153.40	$153.40
Time/turn (min)			2.59	2.59
Cost/turn ($)			$6.62	$6.62
Net value at roadside ($/m³)			$12.19	$4.73
Marginal-turn volume (m³)			0.54	1.40
Logs per turn			1	4
Marginal-log volume (m³)			0.54	0.35

GRAPPLE YARDING HAND-FELLED VERSUS MECHANICALLY FELLED AND BUNCHED TIMBER

The first study in this series monitored a Madill 122 yarding crane as it grapple yarded hand-felled second-growth timber (MacDonald 1987). Some comparisons can be made between results even though the equipment used for the two studies was different (Table 12). Both settings were relatively flat and uniform, although the Madill 122 had the advantage of elevated roads which increased deflection and made hookup easier. The average yarding distance was equal for the two studies.

TABLE 12. Grapple-Yarding Comparison Between Hand-Felled and Mechanically Felled and Bunched Timber

	Hand felled	Mechanically felled and bunched
Site and system		
Yarding crane	Madill 122	Washington 118A
Volume per ha (m^3)	343	382
Terrain	Flat	Flat
Bucking specifications	Log-length	Tree-length
Shift-level results		
Utilization (%)	83.4	83.3
Volume per PMH (m^3)	34.7	62.1
Volume per 8-hr shift (m^3)	232	414
Pieces per PMH	46.0	56.5
Piece average (m^3)	0.75	1.10
Yarding cost ($/$m^3$)	5.68	4.08
Detailed-timing results		
Yarding distance (m)	77	77
Pieces per turn	1.2	2.9
Volume per turn (m^3)	0.9	3.1
Net yarding time per turn (min)	0.95	1.37
Average turn time (min)	1.25	2.16
Move time per turn (min)	0.16	0.64

Both study areas were comprised of Douglas-fir timber of roughly equal age and size, although average piece size was reduced in the case of the Madill 122 because stems were bucked into logs before yarding. The Madill 122 normally yarded single pieces with an average of 1.2 logs per turn, while the Washington 118A normally yarded bunches and averaged 2.9 logs per turn. The average turn volumes were 0.9 m^3 and 3.1 m^3 respectively.

Machine utilization during both studies was approximately 83%, although the Madill 122 spent 80% of its time yarding and 3% moving. The Washington 118 spent 67% of its time yarding and 16% moving. The machines averaged 34.7 and 62.1 m^3 /PMH, or 232 and 414 m^3 /8-hr shift respectively. The average yarding costs were \$5.68 and \$4.16/m^3 .

The average turn time for the Madill 122 was 1.25 min and for the Washington 118A the turn time was 2.16 min; the net yarding times were 0.95 and 1.37 min respectively. The Madill 122 was faster during both yarding and moving. The times for hookup, unhook, and deck were approximately equal, but the outhaul-plus-inhaul time for the Washington 118A was approximately double the time for the Madill 122 (0.74 versus 0.39 min). The regression models for outhaul-plus-inhaul showed the Washington 118A actually had the higher line speed, but it also had a long fixed time per turn to tighten the lines and engage the interlock. The long fixed time caused the Washington 118A to have the longer net yarding time.

The average moving time for the Washington 118A was 0.64 compared to 0.16 min per turn for the Madill 122. Part of the difference is due to the yarding system; since the Washington 118A yarded more pieces per turn, there were fewer turns per setup, and the moving time per turn was increased. The remainder of the difference was caused by the guyline arrangement on the Washington 118A which increased the average time per guyline move.

Although the Washington 118A was slower and more expensive to operate, the combined effect of tree-length yarding in bunches made it more productive and cost efficient than the Madill 122.

CONCLUSIONS

The Washington 118A averaged 62.1 m^3 /PMH, or 414 m^3 /8-hr shift over the study. The average yarding cost was \$4.08/m^3 . During the study period, it averaged 83.3% utilization and 85.8% availability. Average turn time varied from 1.95 to 2.54 min, including yarder and backspar moves and minor delays.

Yarding bunches increased the average number of logs per turn compared to yarding hand-felled timber. During the two weeks of detailed-timing, the Washington 118A averaged 2.9 logs and 3.1 m^3 per turn. The average log size was smaller during Week 2 than in Week 1, but a higher proportion of logs were bunched in Week 2 and the average turn volumes were equal.

Three different grapples were used during the study, although one was used for a short time only. With the remaining two, the average turn volume and productivity increased as bunch size increased. Productivity for the larger grapple continued to increase for all bunches observed, but with the smaller grapple, turn volume was maximized when bunches were approximately 7 m^3 . Further research is required to find the optimum bunch size for the larger grapple, as well as to document the effect of bunch size on the feller-buncher's productivity.

Active yarding occupied only 63% of productive time. The remainder was divided between moving and minor delays. Most of the moving time was for moving guylines; the Washington 118A required two of its three guylines to be moved simultaneously which doubled the amount of work. Modifications to the guyline blocks to allow independent guyline movement should reduce its moving times.

The best correlations for cycle elements were between yarding distance and turn volume and the sum of outhaul-plus-inhaul times. An equation was developed showing outhaul-plus-inhaul times as a function of yarding distance and turn volume. There was some correlation between the number of logs in the turn and the hook-up time, but the correlation was slight, and an average hook-up time was used. The other cycle elements were not dependent on the parameters measured (log angle, bunch volume). A model of the total yarding time was developed which showed turn time as a function of yarding distance and turn volume. The predicted turn times for selected yarding distances were used to calculate productivity per hour.

Marginal-log analysis showed that bunching stems reduced the marginal-log volume. An example showed the marginal volume for J-grade Douglas-fir stems was 0.54 m^3 when yarded individually, and 0.35 m^3 when yarded in bunches of four stems. Since the net value at roadside, and thus the marginal-log volume, was dependent on handling methods in subsequent phases, the marginal volume could not be stated with as much certainty as in the first study in this series. However, the example showed that the marginal volume does not change in the same ratio as the number of logs in the turn. Under the assumed conditions, 39% to 23% of the Douglas-fir J-grade logs were submarginal.

REFERENCES

MacDonald, Jack. 1987. Productivity and profitability of the Madill 122 when grapple yarding B.C. Coastal second-growth timber. FERIC Special Report No. SR-48. Vancouver, B.C. 35 p.

Peterson, J.T. 1987a. Harvesting economics: Grapple yarding second-growth timber. FERIC Technical Report No. TR-75. 26 p.

Peterson, J.T. 1987b. Comparison of three harvesting systems in a Coastal British Columbia second-growth stand. FERIC Technical Report No. TR-73. 50 p.

Peterson, J.T. 1987c. Effect of falling techniques on grapple yarding second-growth timber. FERIC Technical Note No. TN-107. 8 p.

Peterson, J.T. 1988. Harvesting economics: Two case studies of a Cypress 7280B swing yarder. FERIC Technical Note No. TN-115. 20 p.

Phillips, Eric J.; Sauder, Brent J. 1978. Evaluation of the Washington 118 yarder. FERIC Technical Note No. TN-22. 17 p.

APPENDIX I

Machine Costs

	Hitachi Backspar	Washington 118A Yarding Crane
OWNERSHIP COSTS		
Purchase price - as equipped	$100 000	$812 500
Purchase price - lines & rigging		$37 000
Sales tax	6%	6%
Expected life (yr)	10	10
Hours per year (h)	1500	1500
Interest rate (I) %	10	10
Insurance rate (Ins) %	1	1
Purchase price - after tax (P)	$106 000	$900 000
Salvage value (S)=(0.2 * P)	$21 200	$180 000
Average investment (AVI)=(P + S)/2	$63 600	$540 000
Expected life (H)	15 000	15 000
Loss in resale value ($/h)=(P-S)/H	$5.65	$48.00
Interest ($/h)(I*AVI)/h	$4.24	$36.00
Insurance ($/h)(Ins*AVI)/h	$0.42	$3.60
Total ownership costs	$10.31	$87.60
OPERATING AND REPAIR COSTS		
Fuel consumption (L/h)	10	30
Fuel cost ($/L)	$0.40	$0.40
Operating supply cost per year (O)	$1 500	$35 000
Annual repair & maintenance cost (R)	$10 000	$50 000
Operator & hooktender wage ($/h)		$18.13
Wage benefit loading (WBL) %		35
Fuel cost = (L/h)*($/L)	$4.00	$12.00
Lube & oil cost (0.1 * fuel cost)	$0.40	$1.20
Operating supply cost = (O/h)	$1.00	$23.33
Repair & maintenance cost = (R/h)	$6.67	$33.33
Gross labour cost	$0.00	$71.47
Total operating and repair costs ($/h)	$12.07	$141.33
OWNERSHIP AND OPERATING COSTS	$22.38	$228.93

SYSTEM COST excluding interest	$211.07
SYSTEM VARIABLE COST excluding ownership	$153.40

NOTES:

Wage calculations

Operator (includes WBL)	$24.48
Hooktender (includes WBL)	$24.48
Subtotal	$48.96
Operator and hooktender bonus (0.7 h per 8 h @ 1.5 wage rate)	$ 6.43
Landingman @ 75% utilization (includes WBL)	$16.08
Total wages	$71.47

APPENDIX II

Washington 188 Specifications

Engine Size

Washington 118 A	236 kW (318 hp)
Washington 188	333 kW (450 hp)

Machine Dimensions

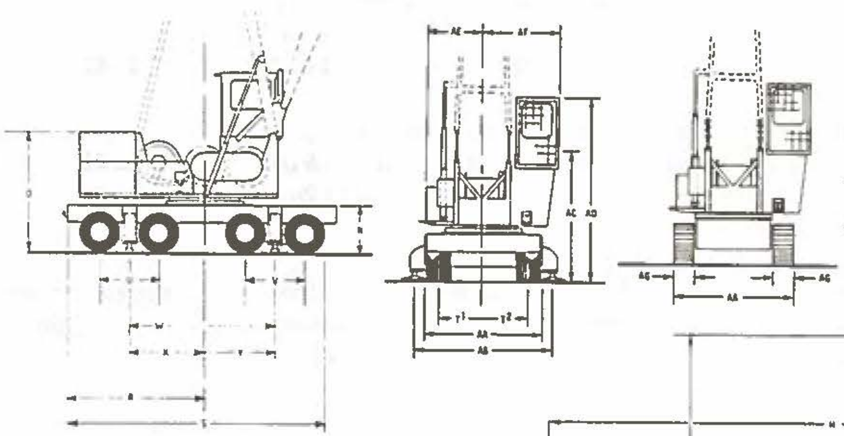
A - 12.0 m (39'6")
G - 16.4 m (53'8")
J - 3.8 m (12'6")
K - 2.1 m (6'9")
P - 4.3 m (14'0")
S - 5.9 m (19'6")
AA - 3.4 m (11'2")
AG - 58 cm (1'11")

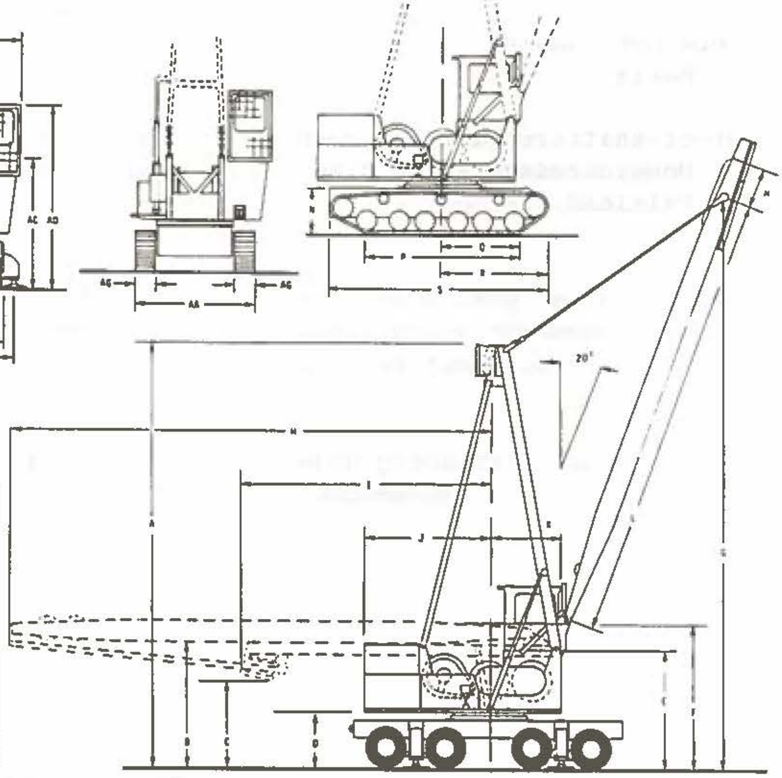
LINE SPEEDS AND PULLS @ 85% EFFICIENCY

DRUMS	MAIN	FRONT	HAULBACK	STRAW	GUYLINE
Maximum Line Pulls (LBS)					
Full	79,200	36,700	19,800	4,000	3,090
Empty	91,200	42,300	25,000	14,300	5,530
Maximum Line Speed (FPM)					
Full	2,045	2,045	3,270	7,450	286
Empty	1,640	1,640	1,970	2,080	180

LINE CAPACITIES

DRUMS	MAIN	FRONT	HAULBACK	STRAWLINE	GUYLINES
Line Capacity (FT-DIA)	2,300'⅞"	2,300'⅞"	4,600'⅞"	4,450'⅜"	180'⅞"





COMPONENT WEIGHTS

BOOM	6,900 lbs.
"A" FRAME	6,500 lbs.
MACHINERY PLATFORM	48,000 lbs.
CARRIER, RUBBER TIRED	35,200 lbs.
CRAWLER	38,500 lbs.
FUEL, LINES AND RIGGING COMPLETE	14,100 lbs.
TOTAL ON RUBBER TIRES	110,700 lbs.
TOTAL ON CRAWLER	114,000 lbs.

APPENDIX III

Summary of Activities

Description	Occurrences	Hours	Average (h)
Productive time			
Prime function	90	124.59	1.38
Move/rig within block	52	29.13	0.56
Change grapple	3	1.72	0.57
Non-mechanical delays			
Move auxiliary equipment	1	0.50	0.50
Unexplained operational delay	4	1.21	0.30
Operator on other activity	1	2.50	2.50
Safety meeting	1	0.45	0.45
Mechanical delays			
Wait for mechanics	1	2.28	2.28
Hydraulic (unspecified) - carrier	1	0.65	0.65
Cable/choker	3	5.99	2.00
Grapple	2	2.87	1.44
Fairlead	2	1.30	0.65
Brakes - winch	3	2.06	0.69
Air lines - interlock	1	0.29	0.29
Air actuators - interlock	3	6.28	2.09
Warm-up	12	2.89	0.24
Daily service	9	1.98	0.22
Clock not running			
Meals	23	14.23	0.62
Out-of-shift repairs			
Undercarriage frame	1	5.00	5.00
Fairlead	1	2.00	2.00

APPENDIX IV

Cycle Element Definitions

Time element	Begins	Ends
Outhaul	When grapple starts travel away from yarder.	When grapple stops at a target log.
Hookup	End of outhaul.	When grapple begins to travel with one or more pieces.
Inhaul	End of hookup.	When incoming turn stops above log deck.
Unhook	End of inhaul.	When grapple has dropped the log and is free to commence next function.
Deck	When yarder grasps a log already in the log deck to straighten or re-pile the deck.	When grapple starts travel away from log deck.
Move yarder or guyline	When grapple stops and crew prepares to move yarder or guylines.	When machinery is in position to commence productive function.
Move backspar or logs	When grapple stops and crew prepares to move backspar or logs.	When machinery is in position to commence productive function.
Delay	When a productive function is interrupted.	When productive function recommences.

APPENDIX V

Tree Scaling Summary

Volume by Butt-Diameter Classes

	Week 1		Week 2		Combined		
Butt-diameter class (cm)	Avg volume (m^3)	Avg length (m)	Avg volume (m^3)	Avg length (m)	Avg volume (m^3)	Avg length (m)	No. of trees
10	0.13	11.2	0.11	10.2	0.12	10.3	35
20	0.33	14.9	0.36	16.7	0.35	16.3	238
30	0.90	20.6	0.87	22.2	0.88	21.4	251
40	1.66	21.9	1.57	22.7	1.62	22.2	113
50	2.39	20.7	2.08	18.6	2.32	20.3	106
60	2.92	12.8	2.77	12.1	2.88	12.6	47
70	3.51	12.4	2.33	8.00	2.92	10.2	4
80	4.79	12.4			4.79	12.4	2
All	1.54	19.1	0.78	18.5	1.12	18.8	796

Douglas-Fir J-Grade Trees Size Distribution[a]

Upper class boundary (m^3)	Percent of trees less than class boundary
0.2	10
0.3	18
0.4	26
0.5	36
0.6	43
0.7	49
0.8	55
0.9	60
1.0	66
All	100

[a] Sample Size 635 trees