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Contents

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Productivity and cost of an Owren 400 hydrostatic yarder

Abstract

During the fall of 1997, the Forest Engineering Research Institute of Canada (FERIC) performed a short-term study of an Owren 400 hydrostatic yarder working near New Hazelton in northwestern B.C. The study provided information about the yarder's productivity and cost. Production functions were derived to predict system performance over a range of operating conditions.

Keywords

Harvesting, Skyline systems, Yarding, Intermediate supports, Productivity, Costs, Interior British Columbia, Owren 400 yarder.

Introduction

Forest management objectives and practices in B.C. are changing rapidly to place stronger emphasis on environmental protection. To minimize harvesting impacts on the environment, new operational strategies and harvesting systems are being developed. On many sensitive sites in interior B.C., where the ground-based harvesting systems cannot meet protective requirements, timber extraction with short-distance skyline yarder systems is a generally accepted alternative. These systems are suitable for both clearcutting and partial cutting applications and can be rigged in running, standing, and gravity skyline configurations. Intermediate supports can be used with all configurations to improve deflection. Because experience with skyline yarder systems and reliable information about their effectiveness and costs are still limited, FERIC conducts an ongoing program in interior B.C. that examines and reports on trial results.

In this operational trial, FERIC observed an Owren 400 hydrostatic yarder, owned by Corduroy Creek Contracting Ltd. and working for Skeena Cellulose Inc., Carnaby Operations, on a handfelled clearcut block near New Hazelton, B.C. This report presents cost and productivity information on using the Owren 400 in a skyline yarding system.

Objectives

The primary goal of this study was to provide current productivity and cost information on a small hydrostatic yarder working in interior B.C. The following specific objectives were established to address this goal:

- Determine productivity and cost for the falling, yarding, processing, and loading phases of the cable-yarding operation.
- Identify factors that influence productivity and cost of the yarding operation.
- Develop productivity and cost functions for the yarding phase.
- Identify operational factors affecting performance of the investigated harvesting system, and recommend improvements where appropriate.

Site description

The case study was conducted in the ICH biogeoclimatic zone of the Prince Rupert Forest Region; specifically, variant 2 of the Moist Cold Interior Cedar-Hemlock ecosystem (ICHmc2) (Banner et al. 1993). The study block monitored by FERIC was located in the Kispiox Forest District, approximately 60 km south of New Hazelton (Figure 1). The mesic to subhygric phases of the ICHmc2 predominate in the study block. Of the total cutblock area of 18.2 ha, 7.5 ha were skyline-yarded, 4.0 ha were skidded with ground-based equipment, and 6.7 ha were in deferred and reserve areas.

Table 1 summarizes the site and stand characteristics of the skyline-yarded unit. The average net merchantable volume of 615 m^3/ha and 1.02 m^3/tree in this unit was far above typical net volumes for the Kispiox district.[1]

Table 1. Site and stand characteristics

Unit area (ha)	7.5
Elevation	
Range (m)	575–700
Average (m)	650
Slope	
Range (%)	30–60
Average (%)	45
Terrain	Broken
Age class	8 (170 yr)
Stand composition (% by volume)	
Western hemlock	45
Hybrid spruce	40
Western red cedar	10
Subalpine fir	3
Lodgepole pine	2
Stand parameters	
Net merchantable volume (m^3/ha)	615
Tree density (no./ha)	603
Net volume (m^3/tree)	1.02
Diameter at breast height (cm)	37
Tree height (m)	35

Machine description

The Owren 400 yarder is a hydrostatic cable-crane unit manufactured by Trygve Owren AS, Lillehammer, Norway, and distributed in Canada by Owren Yarding System Ltd., Prince George, B.C. The yarder is mounted on a Kockum 850 forwarder chassis (Figure 2). Yarder specifications and line capacities are presented in Appendix I. The hydrostatic drive system contains no mechanical components (e.g., clutch, drive line, or brakes) since each drum is powered by its own hydraulic motor. Because of the six-wheel Kockum carrier, the Owren yarder described here is capable of operating at roadside, on landings, and off-road on skid trails.

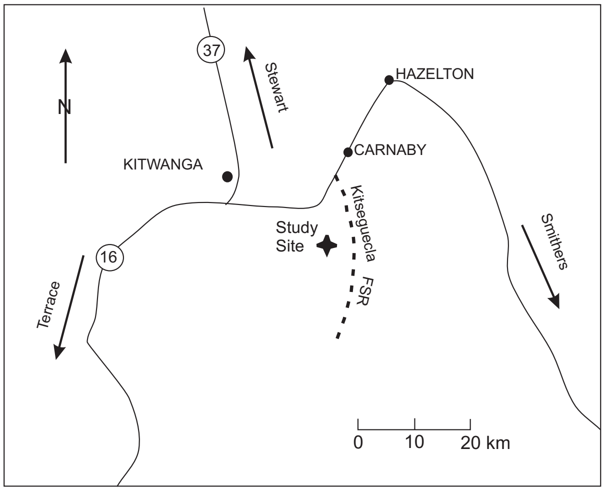

Figure 1. Location of the study site.

[1] Philip Carruthers, Skeena Cellulose Inc., South Hazelton, B.C., and George Burns, Corduroy Creek Contracting Ltd., New Hazelton, B.C., personal communication, July 2000.

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The Owren 400 is suitable for both clearcutting and partial cutting applications and can be rigged in running-, standing-, and gravity-skyline configurations. Intermediate supports can be used with all configurations to improve deflection. The yarder can work with an Owren mechanical slackpulling carriage or other compatible type of carriage for the standing skyline application. The Owren 400 is electro-hydraulically controlled via cable and two joysticks on the freestanding remote control panel that can be positioned up to 40 m away from the yarder.

The yarder operator preferred to use a Koller SKA 2.5 clamping-type carriage (Figure 3) for the yarding roads rigged in the standing skyline configuration, and used the Owren carriage for the running skyline configuration. Both carriages are designed to pass over the intermediate support jack.

A Caterpillar LL 229 loader with butt'n top rotating grapple was used to sort and load the logs.

Figure 2. Owren 400 yarder mounted on a Kockum 850 forwarder.

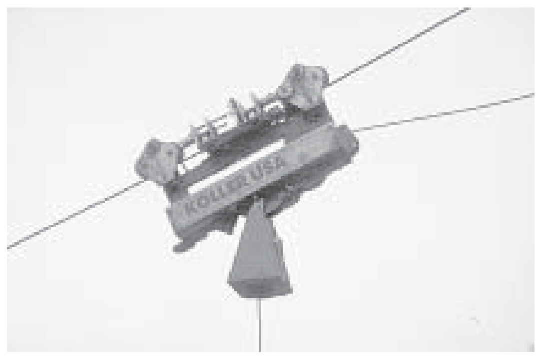


Figure 3. Koller SKA 2.5 carriage.

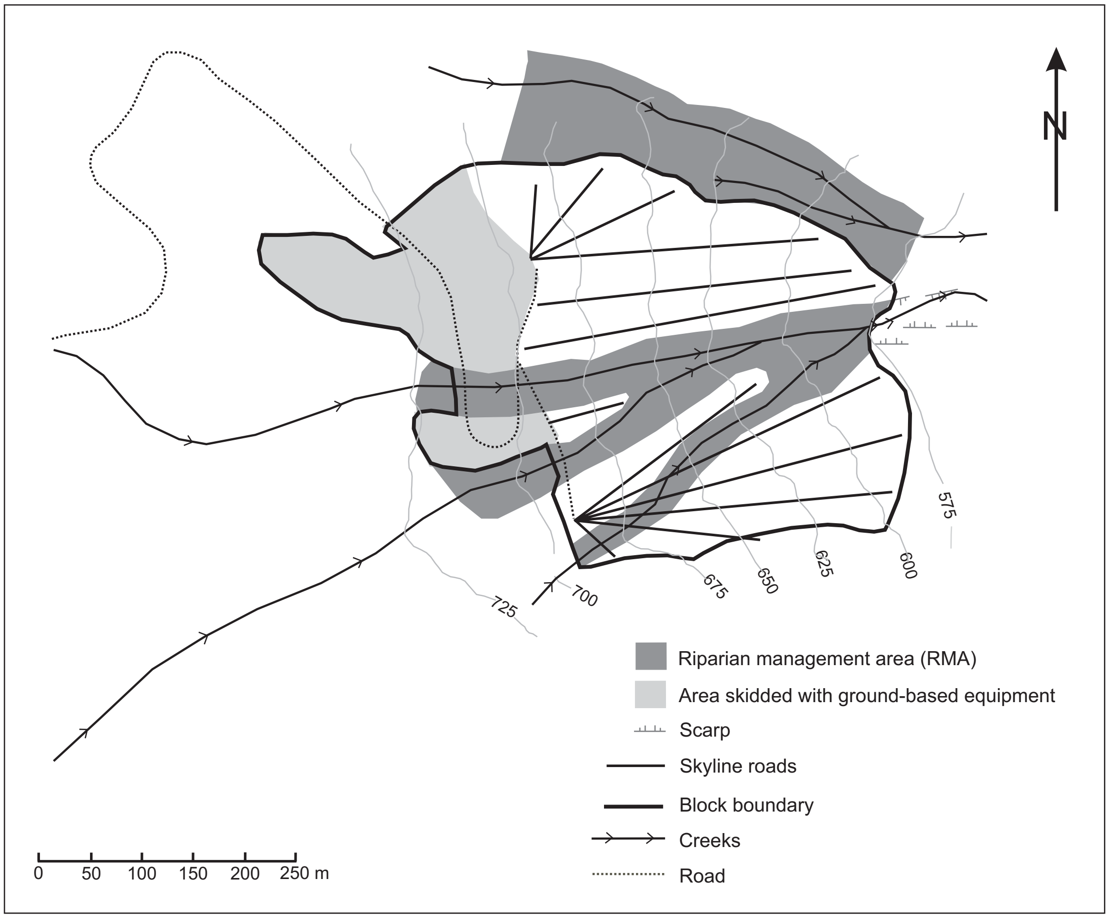
Harvesting system and operations

One faller manually felled the cable-yarded unit with falling downslope where possible. No delimbing or bucking was done in the bush, except for very large trees and those to be yarded across reserve and riparian management areas. The three-person yarding crew consisted of a yarder operator (who also acted as a chaser), a rigging slinger, and a chokersetter. A faller/bucker assisted the yarding crew during the setup and dismantling phases, and rigged the backspars and intermediate supports. The Owren 400 yarder performed the yarding operations, and the faller then processed the stems at the landing. The Caterpillar LL 229 loader cleared the decking area, spread the stems on the road for manual delimbing and bucking, sorted the logs, and loaded the trucks.

Thirteen skyline roads, with lengths ranging from 60 to 380 m (slope distance), were used to harvest the study unit (Figure 4). The Owren 400 worked on the haul roads above the skyline unit and covered yarding roads in as much as a 90-degree arc without repositioning (the maximum coverage is 140 degrees). A standing skyline configuration with uphill yarding was used on eleven yarding roads. Four of these roads were rigged in a single span configuration, and seven used a standing tree as an intermediate support. Two short, almost flat roads were yarded using a running skyline system without intermediate supports.

The yarder operator was provided with maps showing boundaries of the block and riparian management areas, topographic features (contour lines, creeks, ridges, gullies, etc.), and locations of the landings and yarding roads. Ground profiles and

Figure 4. Skyline layout in cutblock.



deflection lines were plotted for all designed yarding roads. To facilitate the road change phase, a supplementary map provided information on location and dimensions (diameter and height) of backspar and intermediate support trees.

The Owren 400 was operated from an external control panel that was positioned close to the road just above the yarding area (Figure 5). Operating the yarder from this location improved the operator's line of sight as the carriage moved toward the tower.

Figure 5. Operator on an external control panel. It can be located up to 40 m away from the yarder.

To improve deflection at the back end of longer yarding roads (>150 m), the skyline was run through a jack strapped at a height of approximately 14 m on the backspar tree, and then anchored to the base of another standing tree. The trees selected for backspars ranged from 50 to 65 cm dbh (diameter at breast height). Two guylines were attached to the backspar above the jack strap rigging point and anchored to stumps or standing trees, to provide additional support during lateral inhaul. On short yarding roads (<150 m), rigging heights on the backspar trees varied from 5 to 12 m. On one road, the skyline was anchored directly to the base of a standing tree.

Each road longer than 150 m also employed one single-tree intermediate support (Figure 6). The hemlock, fir, and spruce trees selected for intermediate supports were straight-boled, 40 to 60 cm in dbh and free of rot. All intermediate supports were constructed as leaning trees, allowing the skyline to hang clear of the base of the tree.

The Koller SKA 2.5 carriage was used in gravity return (shotgun) mode. The rigging slinger spotted the returning carriage by an audible signal to the yarder operator who then stopped the carriage and pulled it back a few metres toward the yarder to set a locking clamp on the skyline. The locked carriage automatically released the mainline and chokers, and the rigging crew manually pulled out the line for lateral yarding. To reduce hookup time, chokers were routinely preset. After hookup, the rigging slinger initiated lateral inhaul until the loaded chokers were pulled into the carriage. This action released the skyline lock and allowed the loaded carriage to be pulled toward the yarder (Figure 7). At roadside, the yarder operator unhooked the turn, and the loader retrieved the yarded stems for processing and piling. In some cases, truck-loading and sorting activities conflicted with yarder-related activities and resulted in delays in clearing the landing for the yarder. In the latter case, large piles of stems accumulated under the skyline, which made the unhooking time of turns difficult and time-consuming.

Backspar and intermediate support trees were not pre-rigged. To change yarding roads, the skyline was lowered, released from the backspar and intermediate support, and respooled. The carriage was locked on the yarder, and the four tower guylines were released and respooled. The backspar and intermediate support were dismantled, and the rigging accessories were moved to the next yarding road. Since the distances between adjacent yarding roads were short, the yarder moved to the next setup without lowering the tower. The yarding crew then pulled the skyline to the back end and rigged the backspar and intermediate support.

Figure 6. Single-tree intermediate support. Loaded Koller carriage has just passed the jack.

Figure 7. Koller carriage with payload.

Figure 8. Rigging the intermediate support.

Rigging the intermediate supports

The intermediate supports were prepared by an experienced crew member in the following steps:

1. Prior to rigging, the tree was delimbed and topped at 12–16 m.
2. Two guylines and two straps were attached and the bypass jack was strapped just below the top of the support (Figure 8).
3. An undercut was made in the tree base in the desired direction of the lean, and the support guylines were installed but not tightened fully.

4. Two sidecuts and a backcut were made to provide the desired lean, with the undercut, sidecuts, and backcut creating a funnel-shaped support for the tree.
5. To ensure the tree remained attached to the stump, some holding wood was left in the centre.
6. Two guylines were tightened and two nylon straps were anchored to large solid stumps (40–85 cm in diameter). Figure 9 show the final rigging configuration.

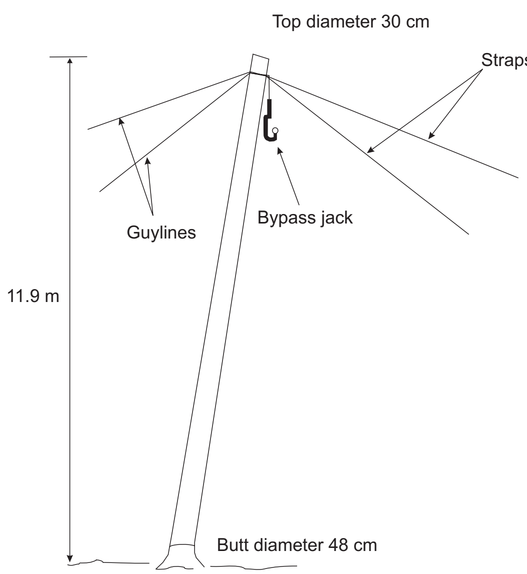


Figure 9. Rigging configuration of intermediate support.

Study methods

FERIC collected shift-level and detailed timing data, number of stems yarded, and scaled log volumes for the study period. The yarder and loader operators completed shift-level reports on a daily basis. They documented shift activities, events, production count, reason for delays and breakdowns greater than 10 min, and comments on factors affecting production. Productivities in m³/scheduled machine hour (SMH) were calculated for each phase based on net volumes and totals of scheduled machine hours (lunch time excluded) for the appropriate phase. Net volumes of logs produced during the shift-level study were summarized from the weigh-scale records.

Yarding cycles were detail-timed at frequent intervals throughout the study period. Each timed yarding cycle was divided into seven timing elements: outhaul, lateral outhaul, hookup, lateral inhaul, inhaul, unhook, and in-cycle delays (Appendix II). In-cycle delays included mechanical and non-mechanical delays of 10 min or less that occurred sporadically in the yarding cycles. Additional data recorded for each cycle were outhaul and inhaul distances, number of stems per cycle, and reasons for observed delays.

The detailed-timing data were analyzed using multiple regression techniques to search for potential relationships between total cycle time and yarding distance, lateral yarding distance, and number of stems per cycle, using a .05 significance level. Equations were then developed to predict delay-free cycle time and to derive production functions to predict hourly yarding productivity (m³/h) and total yarding cost per cubic metre ($/m³). These functions were derived by using an average volume per cycle, and adjusting predicted cycle times to reflect delays encountered in the yarding phase. The first production function estimates average yarding productivity in m³/SMH after the yarder has been installed and is operated routinely. This productivity is needed to predict wood flow and schedule log hauling.

The second production function accounts for rigging time of a yarding road and enables predictions of overall productivity for yarding roads of different characteristics. In this function, the rigging time includes moving the yarder into position, installing and tensioning the skyline, rigging intermediate supports, and dismantling these components after the yarding of the road has been completed.

The overall productivity, hourly yarding costs, and unit falling and loading costs were then applied to generate a chart illustrating the effects of yarding road lengths and widths on the total unit harvesting costs.

Costs for the falling, yarding, and loading phases were calculated using FERIC's standard costing methods (Appendix III). Labour costs were based on Industrial Wood and Allied Workers of Canada (IWA-Canada) rates.

Results and discussion

Productivities and costs

Table 2 summarizes productivities and estimated harvesting costs by phase (falling and processing, yarding, and loading) and in total. Productivities for all phases were similar and in the range of 16 m³/SMH. Overall costs for falling, processing, yarding, and loading were estimated at \$20.43/m³. The most expensive phase was yarding at \$10.96/m³. Of the total harvesting cost, 55% was attributed to labour and 45% to machines. The cost structure by category and phase in this study is similar to cost structures reported by Kockx et al. (1995) and Pavel (1999) for the Rosedale Ecologger II and Skylead C40 16000 yarders, respectively.

Shift-level results

A total of 5750 m³ was harvested from the cable-yarded area. Table 3 provides the dates and number of shifts worked. Table 4 shows the distribution of volumes and stem counts between the standing and running skyline configurations.

Falling and processing

The faller worked a total of 42 shifts, or 344 h, to fall the cable-yarded area and process the stems at roadside. The shift length averaged 8.2 h. Overall, the faller felled and processed 22 stems and 16.7 m³/SMH. The achieved productivity agrees very closely with results presented by Bowden-Dunham (1998) for similar tree sizes. The wood harvested in the study block was of exceptional quality for the Kispiox district: pulpwood constituted only 12% of the harvested volume, and the rest of the wood was processed into high quality sawlogs.[2]

[2] Philip Carruthers, Skeena Cellulose Inc., South Hazelton, B.C., personal communication, December 1997.

Table 2. Productivities and costs by category and phase

Phase	Productivity (m³/SMH)	Cost ($/SMH)	Cost ($/m³)	Cost (%)
Falling and processing				
Labour [a]	-	49.56	2.97	15
Saw allowance [b]	-	4.31	0.26	1
Total falling and processing	16.7	53.87	3.23	16
Yarding				
Labour		101.12	6.20	30
Owren 400 yarder	-	74.61	4.58	22
SKA 2.5 carriage	-	2.97	0.18	1
Total yarding	16.3	178.70	10.96	53
Loading				
Labour	-	31.73	1.98	10
Caterpillar LL 229 log loader	-	68.16	4.26	21
Total loading	16.0	99.89	6.24	31
Total labour cost	-	-	11.15	55
Total machine cost	-	-	9.28	45
Total cost	-	-	20.43	100

[a] Hourly rate based on June 15, 1997 IWA-Canada rates, with 38% for fringe benefit loading.
[b] Saw allowance is based on \$28/6.5-h shift.

Table 3. Dates and shifts worked during harvesting

Work description	Dates (1997)	Productive shifts (no.)
Falling & processing		
Fall trees	August 28–Sept. 2	5
Fall trees, process at roadside [a]	Sept 3–Oct. 20	35
Process at roadside	Oct. 21–Oct. 30	9
Yarding	Sept 3–Oct. 29	43
Loading	Sept. 3–Nov. 5	45

[a] Includes 54 h that the faller spend assisting the yarding crew with setup and dismantling.

Table 4. Summary of shift-level time for the Owren 400 yarder

Element	Standing skyline roads 1 to 11		Running skyline roads 12 & 13		All roads	
	Total	%	Total	%	Total	%
Productive machine hours (PMH)						
Yarding (h)	263	79	14	70	277	79
Road changes (h)	48	15	6	30	54	15
Total PMH	311	94	20	100	331	94
Mechanical delays (MD) (h)	18	5	0	0	18	5
Non-mechanical delays (NMD) (h)	3	1	0	0	3	1
Total all delays (h)	21	6	0	0	21	6
Scheduled machine hours (SMH)	332	100	20	100	352	100
Utilization (PMH/SMH) (%)	-	94	-	100	-	94
Availability (SMH-MDH)/SMH (%)	-	95	-	100	-	95
Volume (m^3)	5 533	-	217	-	5 750	-
Stems (no.)	7 349	-	289	-	7 638	-
Volume (m^3/stem)	0.75	-	0.75	-	0.75	-
Productive shifts (no.)	40	-	3	-	43	-
Productivity						
m^3/productive shift	138	-	72	-	134	-
m^3/PMH	18	-	11	-	17	-
m^3/SMH	17	-	11	-	16	-
m^3/9-h shift	150	-	98	-	147	-

Yarding

The yarder was scheduled to work one 9-h shift per day (lunch time excluded), six days per week. During the 57-day period in which the yarder was monitored, 43 productive and 14 non-productive shifts were recorded. Of the 14 nonproductive shifts, 11 were weekend days off, and 3 shifts were lost while the loader was employed outside of the study block. The shift lengths ranged from 5.5 to 9 h and averaged 8.2 h.

The quality of the block and yarding road layout was satisfactory and no significant problems related to layout occurred. The general layout of yarding roads was kept, and minor adjustments were limited to relocations of the backspar trees.

Table 4 presents the shift-level time distribution for the Owren 400 yarder. For the study period, the yarder's utilization and availability were 94% and 95%, respectively. Most of the delays (85% of total delay time) were caused by mechanical problems. Waiting for the loader to assist unhook activities at the landing was the main reason for non-mechanical delays (Table 5).

Table 5. Summary of shift-level delays for the Owren 400 yarder

Description	Occurrences	Time (h)	Time (%)
Mechanical delays			
Carriage repairs	3	6.2	30
Rigging repairs	12	10.3	50
Service carriage	4	1.1	5
Subtotal	19	17.6	85
Nonmechanical delays			
Operational			
Supervision	2	0.4	2
Organizational			
Wait for other phase	4	1.7	8
Miscellaneous	3	0.9	5
Subtotal	9	3.0	15
Total all delays	28	20.6	100

For all yarding roads and both skyline configurations, the Owren 400 averaged 134 m³/productive shift and 16 m³/SMH (178 stems/productive shift and 22 stems/SMH, respectively). Yarding productivity for the standing skyline configuration (Roads 1 to 11) of 18 m³/PMH was much higher than the productivity for the running skyline configuration (Roads 12 and 13) of 11 m³/PMH. The observed difference in productivities can be attributed to the differences in average load sizes and productive time structures. The average load for the standing skyline configuration with the Koller carriage was 2.6 stems/cycle, and 1.4 stems/cycle for the running skyline configuration with the Owren carriage. Short yarding roads (on average about 100 m) in the running skyline configurations required frequent road changes (30% of the total productive time). For much longer roads in the standing skyline configurations, with an average length of 250 m, the road changes were less frequent (15% of the total productive time). Total yarding cost, combined for both skyline configurations, was $10.96/m³.

In this study, times to rig a yarding road varied from 2 to 8 hours and depended on the skyline configuration, number of intermediate supports, and method of anchoring the skyline to the backspar. Rigging times in Table 6 are based on shift-level records for this study and information provided by the yarder operator.[3]

A direct and precise comparison of costs and productivities of different cable systems is difficult because of differences in stand and terrain conditions of investigated cases, and because of the many advantages and constraints inherent in each cable system. However, to illustrate the relative competitiveness of the Owren 400, a comparison to similar skyline systems was made based on data from previous FERIC studies (Appendix IV). The results show that the productivity of the Owren 400 in this study is comparable with productivity results for yarders of similar size and construction.

Loading

The shift length for the loader ranged from 4.5 to 9.5 h and averaged 8.0 h. Mechanical availability was nearly 100%.

[3] George Burns, Corduroy Creek Contracting Ltd., New Hazelton, B.C., personal communication, October 1997.

Table 6. Rigging time for yarding roads

Rigging configuration	Avg rigging time (h)
Short roads (<100 m) with no intermediate supports; skyline stump-rigged	1
Short roads (<150 m) with no intermediate supports, skyline jack rigged on a tied-back backspar tree	3
Roads >150 m with a single intermediate support, skyline jack rigged on a tied-back backspar tree	6

Table 7. Summary of detailed timing

	Total	%
Productive time		
Yarding (min)	2 103	82
Road changes (min)	210	8
Delays <10 min (min)	267	10
Total productive time (min)	2 580	100
Productive machine hours (PMH)	43	100
Total cycles (no.)	388	-
Total stems (no.)	1 099	-
Total volume (m^3) [a]	824	-
Average load (stems/cycle)	2.8	-
Volume/cycle (m^3) [a]	2.1	-
Average yarding distance (m)	165	-
Average lateral yarding distance (m)	11	-
Productivity		
Cycles/PMH	9.0	-
Stems/PMH	25.6	-
m^3/PMH	19.2	-

[a] Based on an average volume of 0.75 m^3/stem for the shift-level study.

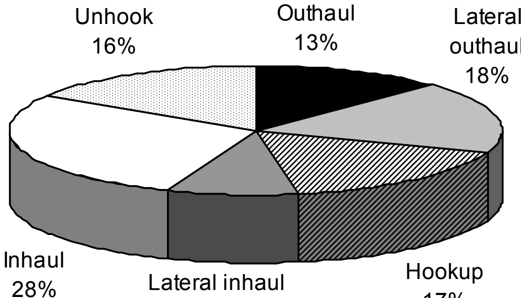


Figure 10. Percent distribution of delay-free cycle time for the Owren 400 yarder.

During the study period, the loader operator recorded only one instance of mechanical downtime of 2 h. The productivity averaged 128 m^3/productive shift (16 m^3/SMH) at a cost of \$6.24/m^3 (Table 2). The loading productivity and cost include all loader activities such as assisting the yarder and sorting logs, as well as loading hauling trucks. Generally, the loader adequately supported the yarder. In some cases, however, yarder-assisting, sorting, and truck loading activities conflicted, resulting in delays in clearing the landing for the yarder.

Detailed-timing results

The Owren yarder was detail-timed for 43 hours, and the study results are summarized in Table 7. A total of 1099 stems and an estimated volume of 824 m^3 were yarded in 388 cycles for a productivity of 19.2 m^3/PMH. Figure 10 presents the distribution of delay-free cycle time (5.42 min) by cycle elements.

The average slope yarding distance for the detailed-timing study was 165 m. Yarded payloads consisted of one to six stems averaging 2.83 stems/cycle. Although the maximum observed lateral yarding distance was 30 m, 75% of lateral yarding occurrences were less than 10 m, and the average lateral yarding distance in this study was 11 m.

Delays of less than ten minutes duration accounted for 10% of the productive time in the detailed-timing study and averaged 0.69 min/cycle. Hang-ups and rehooks, the largest source of delay time, occurred once for every fifth yarding cycle and accounted for 43% of the total delay time. Hang-ups typically occurred when branches of hooked stems were tangled with branches of other felled stems. To avoid overstressing the skyline and support trees, the crew either re-hooked the stems, reduced the cycle payload, or topped the stems with tangled branches. The second most frequent delay during yarding, waiting for the loader to support unhook activities, accounted for 32% of total delay time and occurred in 8% of the timed cycles. This event occurred when the loader was engaged in sorting stems and logs, or loading trucks.

To get more representative information on yarded payloads, numbers of stems per cycle were recorded for an additional 312 cycles, so the total number of observations on payloads increased to 700 cycles. For a total of 1846 stems yarded in 700 cycles, the payload averaged 2.63 stems and 1.97 m^3 per cycle.

Predicted productivities and costs

Yarding cycle time

Multiple regression analysis was performed on 345 detail-timed cycles having complete information. The analysis found a significant linear relationship between delay-free cycle time and the variables of slope yarding distance, lateral yarding distance, and number of stems per cycle (Equation 1 in Appendix V).

Yarding productivity

The shift-level and detailed-timing results were combined to create a model to estimate productivity during scheduled yarding time (Equation 2 in Appendix V). Road-change times are excluded from the model, so it predicts the yarder's hourly productivity after it has been set up and is operating routinely.

Figure 11 shows predicted yarding productivity for the Owren 400 using the values from the 700 cycles recorded in this study (payload of 2.63 stems and 1.97 m^3 per cycle, utilization of 94%, and "in-cycle" delay of 0.69 min/cycle). Productivity calculated by Equation 2 (Appendix V), or read from Figure 11, can be used to predict wood flow and schedule hauling activities after the yarder has been installed and is operating routinely.

Yarding productivity including rigging time

Because rigging is a necessary component of yarding, shift-level and detailed-timing data were used to create a model to estimate yarding productivity including rigging time.

First, Equation 3 (Appendix V) was developed and used to estimate total time to rig and yard a road.

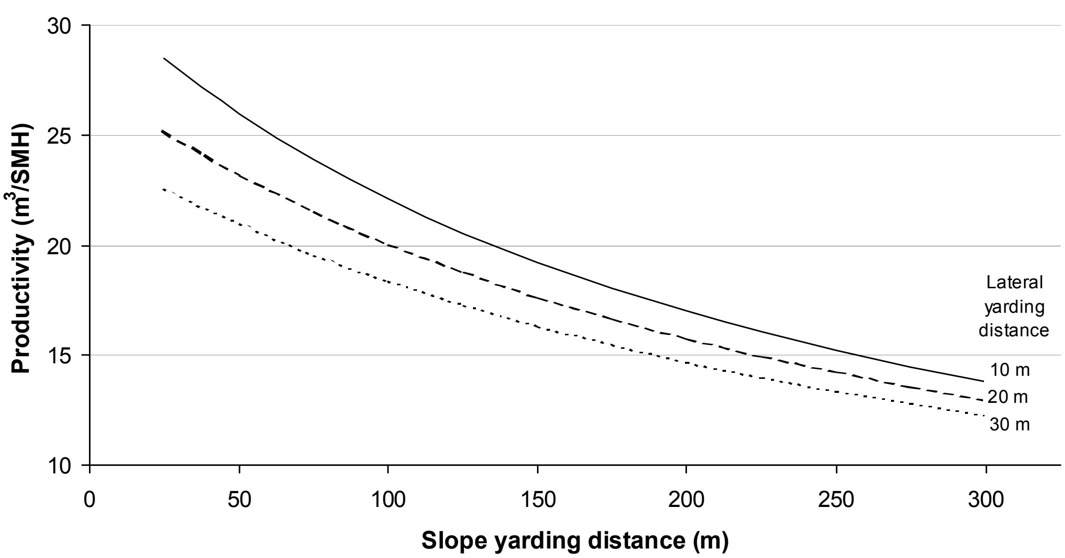


Figure 11. Predicted yarding productivity during scheduled yarding time.

Assuming that the shape of yarding roads was rectangular, and that the stems were distributed evenly over the entire road area, volume extracted from a road was calculated as a product of the yarding road's length, width, and volume of timber in m^3/ha. Rigging time in Equation 3 (Appendix V) included moving the yarder into position, installing and tensioning the skyline, rigging the intermediate support and backspar tree, and dismantling these components after the yarding of the road was completed.

Yarding road time was calculated for an average volume of 760 m^3/ha, road widths from 20 to 60 m, and road lengths from 200 to 350 m, rigged in two-span configuration with a standing tree used as a backspar. For these road lengths, rigging time was not affected significantly by the length of the road and averaged 6 h/road. Equation 4 (Appendix V) is the production function developed to estimate yarding productivity including rigging time.

The graph in Figure 12 shows that the predicted productivity for yarding roads 200–350 m in length, and 20–60 m in width, is in the range of 16–19 m^3/SMH. The predicted yarding productivities calculated in a similar manner for one-span roads are slightly greater (Table 8) because of shorter rigging times (on average 3 h per road) and shorter inhaul distances. Generally, for investigated road lengths, productivity increases with an increase in road widths, and greater productivities can be expected on shorter than on longer roads. The model productivity of 17.3 m^3/SMH calculated for the study block is very close to the yarding productivity of 16.7 m^3/SMH based on shift-level studies.

Figure 12. Predicted yarding productivity including rigging.

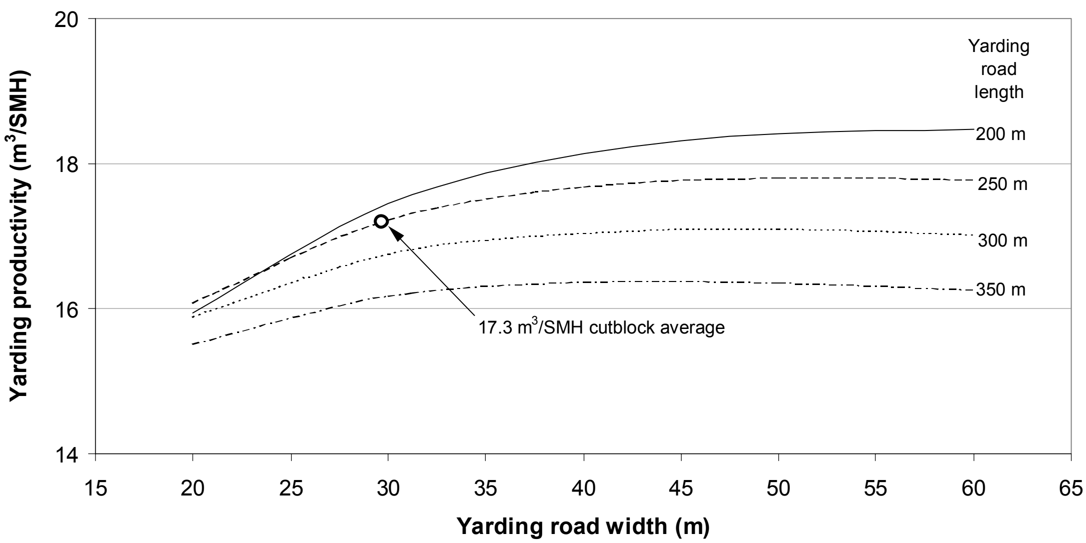


Table 8. Predicted yarding productivities and harvesting costs for typical rigging configurations of the Owren 400 yarder			
Rigging configuration	Predicted yarding productivity (m^3/SMH)	Predicted harvesting cost ($/$m^3$)	Optimum road width (m)
Two-span roads (200–350 m), skyline jack-rigged on a tied-back backspar tree	16–19	19–21	45–60
One-span roads (100–150 m), skyline jack-rigged on a tied-back backspar tree	19–21	18–19	45–60

Unit harvesting costs

To estimate the unit harvesting cost, Equation 5 (Appendix V) was developed.

An hourly yarder cost of $178.70/SMH, and a total of $9.47/m³ for falling and loading (Table 2) phases were applied to generate a chart as shown in Figure 13. This chart illustrates the effects of yarding road length and width on the unit harvesting cost.

The predicted harvesting costs are in the range of $19–21/m³ on the truck. Lower unit harvesting costs can be expected on shorter roads than on longer ones. The chart also shows that road widths affect the unit harvesting costs. Optimum road widths, resulting in minimum harvesting costs, vary from 45 to 60 m. However, moderate deviations from the optimum road widths result in small changes to unit costs. Generally, wider yarding roads result in lower unit costs. The unit cost of $19.80/m³ that was calculated for the two-span configuration is very close to the total cost of $20.43/m³ based on shift-level studies.[4]

Conclusions

The study demonstrates that the Owren 400 is a versatile yarder able to work in a variety of setups. It can be rigged in standing and running-skyline configurations and work with an Owren mechanical slackpulling carriage or with a Koller SKA 2.5 clamping type carriage.

Intermediate supports can be used to improve deflection. On yarding roads from 150 to 380 m, one intermediate support is usually necessary. Both the Owren and Koller carriages are designed to pass over the intermediate support jack.

In this study, the yarding road change times constituted 15% of the total scheduled shift time. On average, 6 h are required to install and dismantle a two-span road (including times to move the yarder into position, raise and lower the skyline, prepare the intermediate support tree, and rig the backspar tree). On short single-span roads (up to 100 m) with stump rigging, the road change times are about one hour. These simple road changes may allow the yarder to economically extract stems from short yarding roads and from small pockets. On correctly designed yarding roads, the extracted loads are semi-suspended, and the soil disturbance can be minimized.

For one- and two-span configurations, yarding productivity including rigging times increases with an increase in road widths, and greater productivities can be expected on shorter than on longer roads.

Unit harvesting costs are affected by road widths. For terrain and stand conditions

[4] The predicted harvesting costs calculated in a similar manner for one-span roads are slightly lower because of shorter rigging times (Table 8).

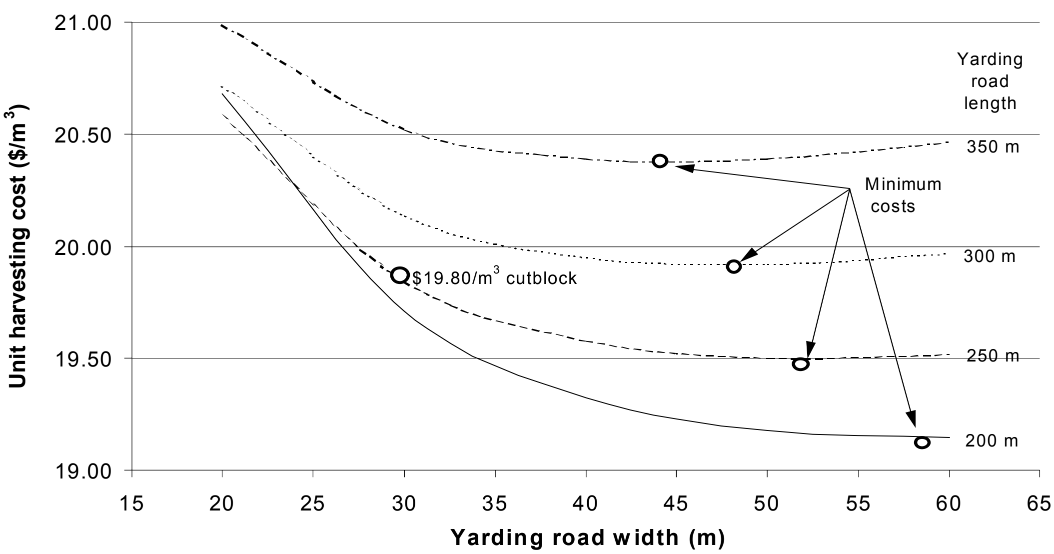


Figure 13. Predicted unit yarding, falling, and loading costs

observed in this project, optimum road widths, resulting in minimum harvesting costs, vary from 45 to 60 m.

For terrain and stand conditions observed in this project, predicted productivities for yarding roads 200–350 m in length, and 20–60 m in width, are in the range of 16–21 m^3/SMH, at total harvesting costs of \$18–21/m^3 on the truck. These excellent results, however, are influenced partially by high net volumes per hectare and per tree, and high quality of the harvested timber.

For one- and two-span configurations, optimum road widths are from 45 to 60 m. Moderate deviation from these widths result in small changes to unit costs.

A comparison to similar small skyline systems showed the productivity of the Owren 400 in this study is comparable with productivity results for yarders of similar size and construction.

Implementation

During the observed harvesting operations, FERIC identified opportunities to improve efficiency and to reduce costs.

- Pre-rigging intermediate support and backspar trees may reduce rigging time, increase overall productivity, and reduce costs. Reduced rigging times should compensate for the cost of additional rigging equipment.
- The leaning single tree support, used in this study, proved reliable. However, different configurations for intermediate supports can be used as well. More information about rigging of intermediate support and backspar trees can be found in Pestal 1961 and Dunham 2000.
- To reduce hang-up and rehook times, the main source of "in-cycle" delays, and to maximize the size of extracted payloads, more delimbing and bucking should be done at the stump.
- To keep the yarding operation with the Owren 400 efficient and safe, a skidder and/or a loader supporting the unhook activities and moving the in-hauled and unhooked stems from the landing to the processing and decking areas are integral components of the harvesting system. The use of the skidder during the first days of yarding, before loading and hauling activities start, may be a cost-effective solution. With increased volume for processing and loading, the use of the loader may be a better option. To improve the loader's efficiency, the planner should investigate into opportunities to expand its employment (e.g., the loader can also be used to assist processing and load the logs in the ground-skidded unit of the block, or serve two yarders if applicable).

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Appendix I

Specifications and line capacities for the Owren 400 yarder

Engine	Deutz, a 6-cylinder turbo-charged, water-cooled diesel engine, 134 kW (180 hp)
Hydraulics	Sauder Sundstrad and Danfoss
Direction	Yarding from the right side of the machine, covering an arc of 140°
Line:	
Mainline	12 mm diameter (1/2 in.), 400 m long
Haulback	12 mm diameter (1/2 in.), 800 m long
Slackpulling	12 mm diameter (1/2 in.), 400 m long
Skyline	19 mm diameter (3/4 in.), 400 long
Rig up line	4 mm diameter (5/32 in.), 800 m long
Straw line	8 mm diameter (5/16 in.), 800 m long
Guyline	19 mm diameter (3/4 in.), 4 × 50 m long
Hoist line	12 mm diameter, 30 m long
Line pull	Max. 6000 kg
Line speed	Variable, from 0 to 8 m/s
Controls	Electro-hydraulic by cable, 2 joysticks
Total weight without carrier	10 500 kg
Total weight with Kockum 850 carrier	24 000 kg

Appendix II

Cycle elements for detailed timing of yarding phase

Outhaul	Begins when the carriage starts travel away from yarder and ends when the signal “stop carriage” is given.
Lateral outhaul	Begins after outhaul and ends when the chokersetter stops to choke the first tree.
Hookup	Begins after lateral outhaul and ends when the signal “inhaul” is given.
Lateral inhaul	Begins after hookup and ends when the chokers are pulled into the carriage.
Inhaul	Begins after lateral inhaul and ends when the incoming turn has finally come to rest at the end of the yarding road.
Unhook	Begins after inhaul and ends when the carriage starts travel away from yarder.
Delay	Begins when a productive function is interrupted and ends when a productive function is recommenced.
Road changes	Begins when a crewman signals start of road change and ends at start of outhaul for first turn on the new yarding road.

Appendix III

Hourly equipment costs for Owren 400 yarding system [a]

	Owren 400 mobile cable-crane	Koller SKA 2.5 carriage	Caterpillar 325 log loader [b]
OWNERSHIP COSTS			
Total purchase price (P) $	395 000	20 280	360 000
Expected life (Y) y	10	10	10
Expected life (H) h	16 000	16 000	16 000
Scheduled hours per year (h)=(H/Y) h	1 600	1 600	1 600
Salvage value as % of P (s) %	30	30	30
Interest rate (Int) %	10	10	10
Insurance rate (Ins) %	3	3	3
Salvage value (S)=(s•P/100) $	118 500	6 084	108 000
Average investment (AVI)=((P+s)/2) $	256 750	13 182	234 000
Loss in resale value ((P-S)/H) $/h	17.28	0.89	15.75
Interest=((Int•AVI)/h) $/h	16.05	0.82	14.63
Insurance=((Ins•AVI)/h) $/h	4.81	0.25	4.39
Total ownership costs (OW) $/h	38.14	1.96	34.76
OPERATING COSTS			
Fuel consumption (F) L/h	38	-	35
Fuel cost (fc) $/L	0.40	-	0.40
Lube and oil as % of fuel cost (fp) %	10	-	10
Annual repair and maintenance [c] (Rp) $	31 600	1 622	28 800
Wages [d] (W) $/h	101.12	-	31.73
Fuel (F•fc) $/h	15.20	-	14.00
Lube and oil ((fp/100)•(F•fc)) $/h	1.52	-	1.40
Repair and maintenance (Rp/h) $/h	19.75	1.01	18.00
Total operating costs (OP) $/h	137.59	1.01	65.13
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	175.73	2.97	99.89

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

[b] The Caterpillar LL 229 used in this study is no longer manufactured. Purchase price used in the cost analysis is based on the Caterpillar LL 325.

[c] Annual repair and maintenance costs are calculated using 80% of the total purchase price divided by the lifetime in years.

[d] Based on three crew members working 43 shifts and one working 6.5 shifts.

Appendix IV

Yarding productivities of small cable systems studied by FERIC

Yarder	Prescription	Average volume (m^3/stem)	Productivity (m^3/SMH)	References
Smith Timbermaster	Clearcut	0.54	15.0	Courteau (1991)
Skylead C40	Partial cut	0.50	17.0	Forrester (1993)
Skylead C40	Clearcut	0.82	19.5	Forrester (1993)
Rosedale Ecologger II	Patch cut	0.61	13.9	Kockx et al. (1995)
Skylead C40 16000	Partial cut	0.47	12.8	Pavel (1999)
Owren 400	Clearcut	0.75	16.3	Current study

Appendix V

Regression analysis, productivities and costs

Equation 1: $CT = 1.94 + 0.0151(SYD) + 0.0511(LYD) + 0.147(SL)$

n = 345 cycles R^2 = 68% $S.E.E.$ = 0.71

where:

CT	=	Delay-free cycle time (min)
SYD	=	Slope yarding distance (m)
LYD	=	Lateral yarding distance (m)
SL	=	Stems yarded per cycle (no.)
n	=	Number of cycles used in the regression analysis
R^2	=	Multiple coefficient of determination
$S.E.E.$	=	Standard error of estimate

This equation is applicable for the following ranges:

- SYD: 20–290 m
- LYD: 0–30 m
- SL: 1–6 stems

Equation 2: $Productivity = \dfrac{60(CV)(U)}{CT + DT}$

where:

Productivity	=	Predicted productivity measured in m³/h (adjusted to account for yarder utilization and "in-cycle" delays)
CV	=	Average volume yarded/cycle (m³)
U	=	Utilization (from Table 4)
CT	=	Cycle time from Equation [1] (min)
DT	=	"In-cycle" delay time/cycle (min)

Equation 3: $YardingRoadTime = (RoadVolume/Productivity) + RiggingTime$

where:

YardingRoadTime	=	Total time to rig and yard a road (SMH)
RoadVolume	=	Total timber volume extracted from a yarding road (m^3)
Productivity	=	Yarding productivity from Equation 2 (m³/SMH)
RiggingTime	=	Time to rig a yarding road (SMH)

Equation 4: $YPIRT = RoadVolume/YardingRoadTime$

where:

YPIRT	=	Yarding productivity including rigging time (m^3/SMH)
RoadVolume	=	Timber volume extracted from a yarding road (m^3)
YardingRoadTime	=	Total time to rig and yard a road from Equation 3 (SMH)

Equation 5: *Unit Harvesting Cost = (Yarder Cost/YPIRT) + Unit Falling and Loading Costs*

where:

UnitHarvestingCost	=	Sum of unit yarding, falling, and loading costs, including rigging cost ($/m³)
YarderCost	=	Hourly yarder cost (including carriage cost) ($/SMH)
YPIRT	=	Yarding productivity including rigging, from Equation 4 (m³/SMH)