Yarding Cost for the Koller K300 Cable Yarder: Results from Field Trials and Simulations

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ABSTRACT. *This paper describes results from field studies and simulation that can be used to estimate the yarding cost for the Koller K300 cable yarder. Yarding costs can be estimated for clearcuts and light and heavy thinnings in eastern hardwoods. Yarding costs can be estimated with a handheld calculator, or the data can be incorporated into stump-to-mill desktop PC and mainframe computer programs. The results can be a valuable tool for loggers, managers, and planners considering the use of small- to medium-size cable yarders to extract timber from eastern hardwood stands. North. J. Appl. For. 13(4):5–9.*

As changing political and public concerns require new ways of managing forested lands, owners of commercial forestlands are investigating ways to harvest or treat their timber stands using several different management objectives. Current emphasis is on harvesting trees by group selection, thinning, shelterwood, and individual-tree selection methods. One objective is to leave more trees standing in the residual stand following harvest to enhance visual and esthetic goals and to provide habitat and niche for a variety of wildlife species.

Also, concern is increasing over the impact of timber harvesting using conventional ground-based harvesting equipment on the forest ecosystem (Huyler and LeDoux 1994). One alternative to ground-based systems operating on steep forested slopes is the use of cable logging technology. Cable logging technology can minimize roading and environmental impacts to the site compared to conventional ground-based systems, but it is also more expensive than ground-based systems to implement.

Logging cost and production estimates have been developed (McIntire 1981, Rossie 1983) and implemented by designing detailed stump-to-mill computerized software (LeDoux 1985, LeDoux 1986a) for cable and ground-based systems. However, as new systems or new applications of existing systems emerge, it is useful to conduct detailed time and motion studies on these systems or applications. Such studies can be used to develop economic information and then see how practical it may be to integrate the results into balancing ecosystem management and biodiversity goals. Accordingly, the Koller K300 was studied in test hardwood sites in Massachusetts to estimate cost and productivity.

Methods

A detailed time and motion study was conducted to estimate the production capability of the cable yarder. Six yarding elements were identified and timed to determine the total delay-free yarding cycle time (Table 1). All times were recorded to the nearest one-tenth of a minute. We estimated the hourly machine rate using standard costing methods. Using 1994 new equipment cost, labor and fuel costs, and the THIN yarding simulation model (LeDoux and Butler 1981), we developed a general equation for estimating yarding cost for the Koller K300 yarder. Table 2 shows the cost per hour

Table 1. Mean, standard deviation, and range of the yarding time elements.

Yarding variables	Mean cycle time (min.)	Standard deviation	Range	
			Low	High
Outhaul	0.431	0.221	0.230	1.50
Wait for chokersetter	0.334	0.570	0.100	2.80
Lateral out	0.661	1.030	0.101	6.08
Hookup	1.221	0.859	0.131	5.00
Lateral-in	0.884	0.728	0.102	4.50
In-haul	1.817	0.579	0.111	3.10
Total cycle time	5.348	2.065	1.320	13.68

Table 2 Hourly yarding costs (1994) for the Koller K300 yarder (includes all new equipment).

Item	Dollars/hr
Yarder, rigging, and carriage	21.72[a]
Three chainsaws	2.31
Labor	40.99[b]
Radio signal (two transmitters)	0.90
Total	65.92

[a] Includes depreciation, insurance, interest, and operating costs (fuel, oil, lubricants, maintenance, repair, and taxes) for the yarder.
[b] Crew of three and includes 35% for fringe benefits.

for equipment and labor based on a three-person crew for the system. The equation developed is applicable in northeastern hardwoods for various combinations of conditions and levels of silvicultural treatments.

Study Site

The study site was located in north-central Massachusetts on the Beartown State Forest. The harvest was offered as a bid contract for a cable yarder timber sale. The bid was for the purchase of approximately 104,000 bd ft and 300 ft^3 of standing timber as marked by a state forester on 30 ac of land. Volume before the harvest was approximately 12.5 mbf/ac. The postharvest volume was approximately 9 mbf/ac with a residual BA of 70 ft^2. Trees removed consisted mostly of overmature, good quality red oak. The remaining stand had heavy proportions of large hemlock, which explains the higher than normal volume/ac for the region. Table 3 shows the tally sheet for approximately 50% of the total sale that contained steep slopes to be harvested with the Koller K300 yarder. The mean slope for the area was approximately 40 to 50%. Skyline corridors averaged about 55% slope with a maximum slope of about 65%.

Table 3. Species and volume marked for cutting on steep slopes

Species	Tree quality	Total bd ft	No. of trees
Red oak	Good	78,575	235
Hemlock	Fair	5,475	21
Red maple	Fair	5,166	32
Yellow birch	Good	4,914	24
Other	Fair	9,546	61

Cycle Time Equation

Regression analysis was performed on the Koller K300 time-study data in order to develop a prediction equation for estimating the cycle time, excluding delays. Variables included slope yarding distance, lateral yarding distance, cubic foot volume per cycle, weight per cycle, number of stems per cycle, and cubic foot stem volume (Table 4). Stem volume was then transformed using the reciprocal to improve the predictiveness of the equation. The coefficient for each of the selected variables used in the cycle time equation is shown at the bottom of Table 4. Also, the percentages of total on site-time for move-in and yarder corridor-change were recorded and are given in Table 4.

A similar study conducted by Rossie (1983) on a national forest timber sale showed about the same results for estimating the cycle time of the Koller K300 yarder. Testing the same four variables as we did in our study for predictive capability of cycle time, Rossie found that two of the four variables, slope yarding distance, and lateral yarding distance, had a significant influence on the outcome of the model. Also, in a study, which integrated a Koller K300 with a rubber tired skidder, McIntire (1981) found similar results in the variables that were significant for predicting the cycle time of the yarder. The significant variables were slope yarding distance, cubic foot volume per turn, and cubic foot stem volume per turn. Table 5 is a comparison of the sample means

Table 4. Sample means, standard deviation, and range of production variables and cycle time equation coefficients.

			Range	
Production variables	Mean	Standard deviation	Low	High
Skyline slope distance (ft)	426.00	196.822	100.00	675.00
Lateral yarding distance (ft)	27.70	34.468	0.00	150.00
Number of stems per cycle	1.20	0.382	1.00	3.00
Volume per cycle (ft^3)	35.17	14.086	13.01	92.08
Weight per cycle (lb)	2,138.90	872.910	815.50	3,415.78
Percent of total on-site time for move-in/out and corridor change	—	—	—	14.10%

Prediction equation (excluding delays) for cycle time in minutes

Unit	Constant	Slope yarding dist.	Lateral distance	Vol. per cycle	$\frac{1}{\text{Stem vol. } (ft^3)}$	R^2	SE
Koller K300	$\hat{y} = 0.223$	$0.004x_1$**	$0.024x_2$**	$0.059x_3$**	$35.23x_4$*	0.625	1.265

* Significant at the 0.05% level.
** $P < 0.01$.

Table 5 Comparison of sample means and standard deviation for significant yarding variables on selected yarding studies.

Variable		K300 Rossie	K300 McIntire	K300 Huyler-LeDoux
Slope yarding distance (ft)	Mean	382	300	426
	Std. dev.	137	Ng*	196
Lateral yarding distance (ft)	Mean	45	Ng*	27
	Std. dev.	35	Ng*	34
Volume per turn (ft^3)	Mean	36	23	35
	Std. dev.	18	Ng*	14
No. of stems per turn	Mean	1.60	2.0	1.20
	Std. dev.	0.63	Ng*	0.38

* Not given.

and the standard deviation of the yarding variables for three selected studies of the Koller K300 yarder.

Yarding Cost Equation

Simulated, delay-free data points for yarding cost were developed for the Koller K300 yarder over a range of diameters (dbh), average slope yarding distance (SYD), and volume cut/ac (VOAC). The stands chosen were from forest model plots of eastern hardwoods (Table 6) (1 ac forest model plots, unpubl. data, USDA For. Serv., 180 Canfield Street, Morgantown, WV 26505). Each stand was thinned using a *d/D* ratio (arithmetic mean stand diameter of cut trees/arithmetic mean stand diameter) of 1.0 to levels of 30%, 50%, and clearcut. The trees cut from each treatment were bucked into logs (LeDoux 1986b). Table 7 summarizes the log populations by forest model plot. The THIN model (LeDoux and Butler 1981) and time study data from our study of the Koller K300 yarder were used to develop the delay-free data points through several simulations. The simulated data points were pooled to develop a delay-free cost equation for the Koller K300 yarder. Nonlinear regression analysis was used to estimate the delay-free points and the independent variables. The equation takes the form:

$$\begin{aligned}\text{Dollars/ft}^3 = {} & 0.361880 - 0.020344(\text{dbh}) \\ & + 0.0000123(\text{VOAC}) \\ & + 501.194115(1/(\text{VOAC} * \text{dbh})) \\ & + 0.000372(\text{SYD})\end{aligned}$$

$R2 = 0.666$

Table 6. Stand data for six forest model plots.

Plot	Average dbh[a] (in)	Merchantable volume[b] (ft)	No. of trees/ac
A2	7.2	2,652	222
B10	8.1	2,528	214
C8	9.1	3,556	245
D14	11.6	3,124	166
E13	12.7	4,922	183
F4	16.8	6,315	176

[a] Includes trees 5.0 in. or larger in dbh.
[b] Logs less than 4 ft long and less than 4 in. top diameter not included.

where

dbh = arithmetic mean tree dbh (in.),

variable limits = 4.0 to 17.0 in.,

SYD = average slope yarding distance (ft) variable limits = 50 to 900 ft, and

VOAC = average volume (ft^3) removed/ac variable limits = 780 to 6,871 ft^3.

The equation is machine-specific, and the variable limits should be observed carefully.

As an example of the application of this yarding cost equation, the logger or forest planner needs to know: (1) the mean tree dbh on the stand within the variable limits of 4.0 to 17.0 in.; (2) the average volume cut/ac in ft^3 within limits of 780 to 6,871 ft^3 (VOAC); and (3) the limits of 50 to 900 ft average slope yarding distance (SYD). This yarding cost estimate can be used as one of the components in a stump-to-mill timber cost estimate (LeDoux 1985). Other components required for a complete stump-to-mill cost estimate are felling, limbing and bucking costs, yarding delay costs, loading cost, and hauling cost to the mill.

Yarding Delays

The productive time for the Koller K300 yarder was about 65% of the total on-site time. Three categories were used for delay times: (1) operational delays, (2) mechanical delays, and (3) nonproductive delays. From Figure 1, operational delays accounted for 21% of the total cycle time and represent delays associated with the main operational functions of the system. For example, the predominant delays were caused by chokers caught either at the log deck or in the lateral yarding hookup element. Similarly, waiting for chokesetter and choker release failures at the log landing also caused delays. Mechanical delays or mechanical failures of the system accounted for 10% of the total cycle time. Examples were mainline breaks, mechanical failures of carriage, and hydraulic line failures. The third category, nonproductive delays, accounted for 4% of the total cycle. These delays were associated

Table 7 Log size parameters, volumes/ac, and logs/ac, by harvest treatment and forest model plots

Plot	Harvest treatment	Log size[a] Mean	Minimum	Maximum	Standard deviation	Volume/ac	Logs/ac
				(ft^3)			
A2	Clearcut	11.2	0.7	48.8	13.2	2,476	764
	50% thinning					1,238	382
	30% thinning					817	251
B10	Clearcut	11.6	0.7	45.1	11.5	2,481	736
	50% thinning					1,240	368
	30% thinning					818	240
C8	Clearcut	13.7	0.7	48.2	12.9	3,360	843
	50% thinning					1,680	420
	30% thinning					1,108	279
D14	Clearcut	17.7	0.7	49.2	14.4	2945	571
	50% thinning					1,472	285
	30% thinning					972	189
E13	Clearcut	25.2	0.5	66.6	15.7	4,612	629
	50% thinning					2,306	316
	30% thinning					1,521	206
F4	Clearcut	33.1	0.5	54.8	14.4	5,834	605
	50% thinning					2,917	302
	30% thinning					1,925	199

[a] Log-size parameters remained the same for each treatment by plot.

with personal time and talking with either crew members or the on-site forester.

Environmental delays are another category that will most likely become an important part of estimating total delay time, and therefore costs in the future. These would include weather- related delays and delays associated with compliance with Best Management Practices (BMPs) in a harvesting operation. Although these delays did not occur during the study period reported, they should be a consideration when estimating the annual productive hours of operation. Cable yarding has the distinct advantage over other types of harvesting of minimizing the number of skid roads which reduces the amount of skid trail erosion and sediment production. Therefore, cable yarding should reduce the cost of environmental delays.

Delay percentage is important to any harvesting operation because it has a direct impact on the final cost of production. Delay percentage can be used to adjust the delay-free production equation and therefore the cost equation. As an example, we estimate the yarding cost of the Koller K300 for a northern hardwood stand with an average arithmetic tree dbh of 10 in., average slope yarding distance of 400 ft, and average volume removed/ac of 1,240 ft^3. The delay-free yarding cost is:

$$\begin{aligned}\text{Dollars/ft}^3 &= 0.361880 - 0.02034(10)\\ &\quad + 0.0000123(1240)\\ &\quad + 501.194115(1/(1240*10)) + 0.000372(400)\\ &= \$0.363\end{aligned}$$

Adjusting the delay-free cost with our delay percentage of 35% equals \$0.363/(1–0.35) or \$0.56/ft^3. Delay-free cost may be adjusted to meet other observed delays for the Koller K300 yarder.

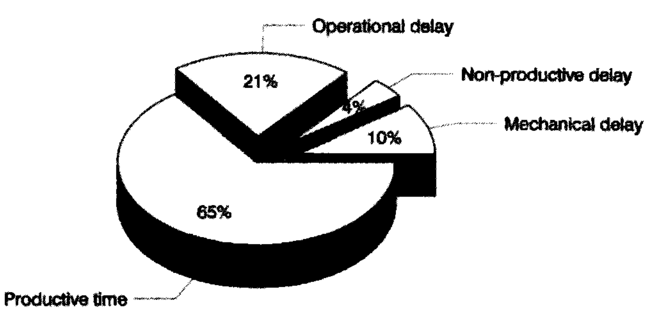

Figure 1. Percent distribution of delay time.

Results and Discussion

As with many of the small- to medium-cable yarders on the market, the delay-free cost/unit volume is sensitive to volume cut/ac, the average slope yarding distance, and piece size or volume. This information can be obtained from the stand inventory analysis and the harvesting plan for the tract to be harvested. Figure 2 shows the impact of volume harvested/ac based on a clearcut and a light and heavy thinning operation. A high volume/ac removal such as the clearcut reduces the yarding cost, while a light volume removal increases cost because of the reduced production efficiency. For example, in planning for a harvesting contract, it is determined that the logger would be allowed \$.22/ft^3 for the harvesting operation. From Figure 2, projecting a line down from the cost curves, shows that before a profit occurs, the stand to be harvested requires at least a dbh of 10.0, 11.5, and 12.5 in. for a clearcut, medium, or light thinning, respectively

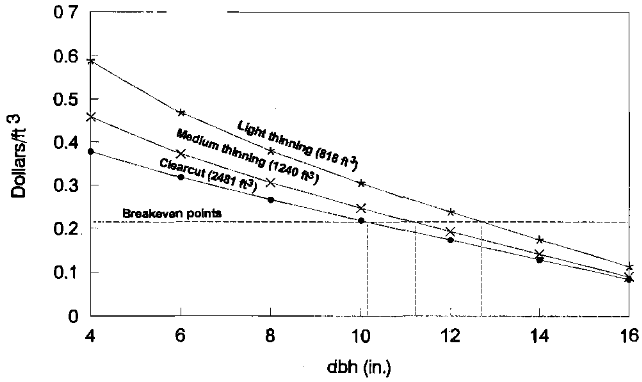

Figure 2. Yarding cost and breakeven points by silvicultural treatment for Koller K300 yarder.

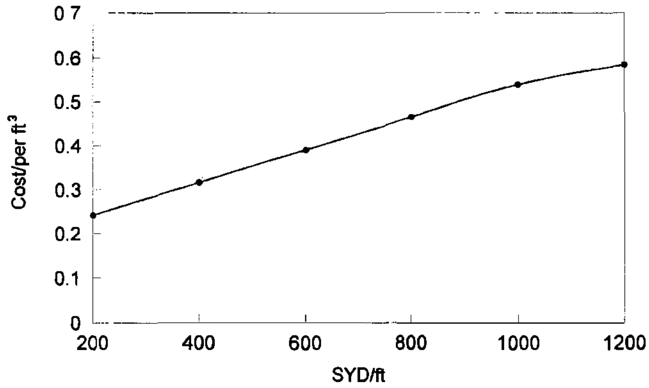

Figure 3. Cost /ft^3 for Koller K300 yarder at various yarding distances (conditions: VOAC = 1240; mean dbh = 12 in.)

Increasing average slope yarding distance will increase delay-free yarding cost. Figure 3 demonstrates the impact of yarding distance on cost/ft^3 of material removed. We held the volume removed/ac constant for a heavy thinning at 1,240 ft^3 and the mean dbh of 12 in. As the average slope yarding distance increases, the cost/ft^3 of material increases. In this study, yarding distances that were greater than 400 ft would be cost prohibitive for the low- to medium-value product yield, such as pulpwood and/or small hardwood sawlogs. It should be noted that other harvesting situations would likely have different yarding distance outcomes. Another factor that influences the yarding cost is payload. The Koller K300 has a recommended payload of 3,000 pounds. In our field study, the mean payload was 2,138 pounds with a minimum load of 815 pounds and a maximum of 3,415 pounds.

Forest managers and loggers who plan to utilize small cable yarding for harvesting must know which factors will affect the outcome of the operation. Generally, the factors discussed in this study such as volume cut/ac, average tree dbh, average slope yarding distance, and number of stems or payload are the important factors to be considered.

Conclusion

Compared to conventional ground-based skidding operations, small- to medium-cable yarders for light and medium thinnings or clearcuts in northern hardwoods on steep slopes are generally more expensive. The hourly yarding cost for the Koller K300 was estimated to be $65.92 for a crew of three workers. The yarding delays for operational, mechanical, and nonproductive time accounted for approximately 35% of the total cycle time. Therefore, delays were and should be factored into the delay-free time to give an estimate of the total cycle time.

The Koller K300 yarder cost equation is both machine-specific and site-specific. Other cable yarders on different timber sales may experience more or less costs and delay-free times. However, using the production data to develop simulations in conjunction with cost equations gives forest managers and decision makers a tool for use with other similar harvesting operations. Most operations will be economical when operating in a high-product yield stand and when all factors affecting costs of operations have been evaluated carefully. Cable yarding also has the advantage of minimizing the impact in environmental sensitive areas and can be integrated into biodiversity goals and ecosystem management plans.

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