Production Equations for Tower Yarding in Coastal British Columbia

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ABSTRACT

Cable yarding is an important means for primary extraction of timber on steep slopes and/or sensitive soils throughout the world. Comprehensive planning for cable yarding requires detailed production and cost estimates which can be made using production equations. Such equations can come from the literature or independent time studies. Both options depend on previously published studies either for direct use or to improve study design. An elemental time study was designed and used in an investigation of tower yarding in coastal British Columbia. A comprehensive statistical analysis was applied to the data including stratification, fitting regression equations, and hypothesis testing. The findings include a library of production equations applicable over a wide range of operating conditions.

Keywords: *production equations, cable yarding.*

INTRODUCTION

Cable yarding with steel spars is an important means for primary extraction of timber located on steep slopes and/or sensitive soils throughout the world. Cable yarding systems are both expensive and complicated, consequently careful planning is required prior to use including detailed costing and optimal road spacing. Detailed costing depends on estimates of site-specific system productivity which can be made using production equations [3,6]. Production equations are also required in studies of optimal road spacing for cost control. Production equations can be derived from time study data collected independently for each system; however, such studies are expensive and time consuming. If this approach is chosen, the design of the study can benefit from previous studies on cable yarding by guiding the choice of factors to measure and providing the data required for preliminary estimates of sample sizes [5].

Alternatively, production equations available in the literature can be used to estimate system productivity. Researchers have shown that published equations can be used over a wider range of equipment than perhaps generally thought [3,7]. This approach offers considerable cost savings over independent production studies.

A study of logging operations in Coastal British Columbia (B.C.) was initiated in the summer of 1987 by the University of B.C. Faculty of Forestry. The objectives of the study were to develop a "library" of production equations for timber harvesting operations in steep terrain on sensitive soils, and to identify the most important factors which affect system productivity to assist future researchers in study design. The results from studies made on grapple yarding operations were published previously [2]. This paper reports on the results of the studies made on tower yarding which includes both highlead and skyline rigged steel spars.

METHODS OF STUDY AND ANALYSIS

An elemental time study was designed for tower yarding. The work cycle was divided into seven elements defined in Table 1. The methods used to collect data on site and operational variables and for recording and processing the time element data were identical to those used in the study of grapple yarding [2]. Terrain roughness was divided into 4 classes and estimated visually using the classification system shown in Table 2. The methods documented in the grapple yarding study [2] were employed in the analysis of the time study data which included screening for spurious data, stratification, exploratory regression analysis, and hypothesis testing among strata for each element.

Field sites were stratified according to rigging method. A conventional highlead system was used for two of the three strata. A mobile backspar was used for one, while tailblocks were rigged to stumps for the other. The remaining stratum was a gravity feed or shotgun skyline system. With this system, gravity moves the carriage down the skyline during OUTHAUL; consequently adverse slope (uphill yarding) is required. The mainline is used to position and control the speed of the carriage and to yard the turns. A complete description of the strata is

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Table 1. Description of time elements for tower yarding.

Element	Description / Endpoint
OUTHAUL	When the lines begin to tighten and the butt rigging moves away from tower, ending when the butt rigging stops moving.
CHOKE	When the chokermen set the chokers, including walking in to the turn, slacking the lines, and walking into the clear. CHOKE ends when the hooktender signals to go ahead.
INHAUL	When the lines begin to tighten and the butt rigging starts to move towards the tower, ending when the butt rigging stops moving.
UNHOOK	When the lines are slackened to allow the turn to lay safely in the landing and the chaser unhooks the turn from the chokers, ending when the chaser has moved into the clear and given the signal to go ahead.
DECK	When the turn is lifted and positioned in the landing, ending when the lines are slackened and the chaser moves in to unhook the turn.
MOVE	When the straw line is run out from the tower or any blocks are moved at the back-end, or the mobile backspar is moved to change roads, ending when the go ahead signal is given and the butt rigging starts to move or regular production is resumed.
DELAY	When the tower or the production crew are engaged in a function other than those listed above, ending when normal production resumes.

given in Table 3. The yarders observed during the study were all Madill steel spars. The specifications for the machines are given in Table 4.

Table 2. Terrain roughness classification.

	Terrain Class			
Obstacle	1	2	3	4
Depth/Height (m)	(# of obstacles per 100 m2)			
< 1.0	< 4	4 - 40	> 40	–
1.0 - 2.0	–	< 4	4 - 40	> 40
2.0 - 3.0	–	–	0 - 40	> 40
> 3.0	–	–	< 4	> 40

RESULTS

The results of the statistical analysis are presented in Tables 5, 6 and 7. Regression equations are shown for elements which were found to be correlated with one or more site or operational variables. The equation producing the highest coefficient of determination for each stratum is given. Equations were also fitted to data pooled for the strata. Mean times are provided for element-stratum combinations not correlated with any of the measured independent variables. The ranges for the independent variables and other summary statistics are also provided for each model or mean time.

OUTHAUL times were regressed against distance, slope, and terrain. Different functional forms resulted in the best fits for the three strata defined in Table 3; consequently separate equations are given for each stratum. Lack of variation in observed slope and terrain led to nonsignificant relationships for these variables in stratum 2. The best model for the pooled data included distance and slope as predictors.

An equation was fitted for CHOKE to predict times per turn as a function of load volume for strata 1 and 3. Hypothesis testing showed nonsignificant differences between the two strata. Nonsignificant relationships were found for stratum 2 and all of the variables tried, which included number of pieces, slope, and terrain. An equation was fitted to the pooled data for the three strata which showed CHOKE time as a function of the product (interaction) of slope and number of pieces.

Table 3. Description of strata.

Stratum	Definition	
1	Rigging:	highlead, stump rigged
	Machine:	Madill 009
	Slope*:	-85 to 65%
	Terrain classes:	2 - 4,
	Distance range:	20 - 300 m
	Turn volume range:	0.3 - 16.2 m^3
	Crew size:	6
	Days of observation:	19
2	Rigging:	shotgun, stump rigged
	Machine:	Madill 046
	Slope:	-50 to 40%
	Terrain class:	2
	Distance range:	35 - 325 m
	Turn volume range:	2.2 - 24.4 m^3
	Crew size:	6
	Days of observation:	7
3	Rigging:	highlead, mobile backspar
	Machine:	Madill 009
	Slope:	-35 to 75%
	Terrain class:	3
	Distance range:	35 - 285 m
	Turn volume range:	0.9 - 15.9 m^3
	Crew size:	6
	Days of observation:	4

* Negative slope values are adverse for INHAUL, positive values are favourable for INHAUL.

Table 4. Machine specifications for madill towers.

Variable of Interest	Model # 009	Model # 046
Year	1972-76	1980
H.P	525	525
Mainline pull, low gear, bare drum (kg)	26,082	65,968
Mainline max speed, low gear, bare drum (m/min)	187	153
Boom Height (m)	27.7	36.9
Weight (kg)	41,560	57,770

Load volume was the best predictor for UNHOOK times for two of the strata and the model fitted to the data pooled for the three strata. Hypothesis testing led to the pooling of data for strata 1 and 2. UNHOOK times for stratum 3 showed nonsignificant correlations with all of the measured independent variables.

INHAUL times were regressed against distance, slope, terrain, load volume and number of pieces. The mixed estimator [4] was used in the analysis. Load volume consistently resulted in a better model than number of pieces. Slope and terrain showed nonsignificant correlations for strata 2 and 3 due to the lack of variation in these two variables for these strata. The square of distance resulted in the best fit for stratum 1. The model fitted to the pooled data included distance, slope, terrain, and load volume as predictors.

Table 5. Models for estimating OUTHAUL, CHOKE and UNHOOK time (min. per turn) for tower yarding.

Element/ Stratum	Model/ Mean, Minimum, Maximum	R^2	SD/ SE	N	—— Range of Variables ——		
OUTHAUL					**Sl (%)**	**Ter**	**Dist (m)**
1	.205181 + .002887*Dist - .001002*Sl . -.026911*Ter	428	.2026	886	-85-65	2 - 4	20-300
2	.469912 + .000005*$Dist^2$	.200	.2537	261			35-325
3	.088359 + .001904*Dist - .005556*Sl	.187	.2337	166	-35-75		35-285
All	.196393 + .002410*Dist - .000710*Sl	.359	.2245	1310	-85-65		20-300
CHOKE					**Sl (%)**	**Vol (m^3)**	**Numlogs**
1 3	3.168127 + 0.147777*Vol 2.464806	.126	1.3918	151		0.3-16.2	
2	3.273 0.297 9.577		1.2095	267			
All	3.162540 + 0.002006*Sl*Numlogs	.005	1.4761	1215	15-85		1-7
UNHOOK					**Vol (m^3)**		
1&2	0.670761 + 0.036156*Vol	.131	0.5111	187	0.3-24.4		
3	1.176 0.268 5.211		0.7813	154			
All	0.658840 + 0.034684*Vol	.118	0.5016	224	0.3-24.4		

In Tables 5, 6, and 7 abbreviations are: Dist = Distance; Sl = Slope (negative values are adverse for INHAUL, positive values are favourable for INHAUL); Ter = Terrain; Vol = Load Volume; Numlogs = Number of Pieces; N = Sample Size; SD = Standard Deviation; SE = Standard Error; All = Data from All Strata Combined.

Table 6. Models for estimating INHAUL times (min.) per turn for tower yarding.

Stratum	Model	R^2	SE	N Vol	N Dist	Range of Variables			
						Sl (%)	Ter	Dist (m)	Vol (m^3)
1	.334184 + .000029*Dist² - .001463*Sl + .083235*Vol	.304	.6351	112	832	-85-65	2-4	20-300	0.3-16.2
2*	+ .003910*Dist							35-325	
	.157114 + .035099*Vol	.545	.3054	109	301				0.9-24.4
3*	+ .005599*Dist							35-285	
All	.220276 + .006322*Dist - .001377*Sl + .016243*Vol	.350	.5055	221	1053	-85-65	2-4	20-325	0.3-24.4

* The constant and coefficient for Vol are shared for strata 2 and 3.

Table 7. Summary statistics for DECK, MOVE and DELAY times (min. per turn) for tower yarding.

Element/ Stratum	Mean	Min.	Max.	SD	N
DECK [1]					
1	0.008114	0.0	6.405	0.1837	1389
2	1.251487	0.0	8.840	2.4630	39
All	0.485242	0.0	8.840	0.4852	1428
MOVE					
All	0.432159	0.0	5.672	2.5442	1383
DELAY					
All	0.572639	0.0	28.973	2.2060	1384

[1] Strata are: 1 - loading hot, 2 - cold decking.

Results for the elements DECK, MOVE, and DELAY are shown in Table 7. Observed times were expressed as mean times (min per turn) for these three elements. Two strata were defined for deck which were independent of the rigging method: loading hot, and cold decking. For most of the operations observed, loading was done hot, meaning a loader worked in tandem with the yarder to clear the landing area and load trucks. On one operation the loader broke down; consequently turns had to be cold-decked. DECK times were not significantly correlated with any of the measured independent variables. Mean times for the two strata were found to be significantly different. Hypothesis testing resulted in pooling of the data across strata for both DELAY and MOVE. DELAY included operational, mechanical and personnel delays. Mechanical delays and moves in excess of 30 minutes were excluded.

DISCUSSION

For OUTHAUL, the second order functional form in distance gave a higher coefficient of determination than the linear model for stratum 2 (shotgun). This system relies on gravity for transporting the butt rigging from the landing to the felled timber. The load (amount of mainline) increases with increased distance; consequently velocity declines under a fixed force, gravity. Slope had no demonstrable effect on OUTHAUL times for this stratum owing to the lack of variation observed for this variable. Slope had a negative effect on OUTHAUL times for the remaining two strata. Negative slopes represent adverse (uphill) yarding during INHAUL, but favorable (downhill) during OUTHAUL. Apparently the need for increased braking to control the butt rigging resulted in the negative coefficient for slope.

A weak but significant positive relationship was found between CHOKE time and load volume. Clearly chokermen require more time to set chokers on larger pieces or if the load contains more pieces. The combined model also showed a positive correlation with slope. The absolute value of slope was used in this regression. Logically, on steep slopes chokermen require additional time to set chokers owing to the increased difficulty in maneuvering. A weak positive relationship between UNHOOK times and load volume was also found. Workers require more time to retrieve chokers from bigger loads because maneuvering around large or numerous pieces is more difficult.

INHAUL was positively correlated with distance, terrain, and load volume, but negatively correlated with slope. Understandably, longer distances and larger loads led to longer INHAUL times. Rough terrain increased the number of hangups, and operators attempted to control damage in difficult terrain which resulted in longer INHAUL times. Logically, INHAUL was negatively correlated with slope as adverse yarding (negative slope values) led to longer observed times while favorable yarding resulted in shorter times.

The average DECK time per turn was found to be higher when cold decking pieces than when loading hot. The landing area became crowded quickly during cold decking which led to a greater amount of time spent maneuvering pieces to make room for the next turn. Cold decking is not the standard practice on tower operations.

ESTIMATING CYCLE TIMES

Detailed descriptions of the use of production equations for predicting site-specific system productivity are available [1,6]. Once the choice is made to use the equations from a particular study, the process continues with the estimation of cycle times. The use of the data presented here to predict cycle times can be described in three steps. First, rigging conditions and terrain for the setting under study

Table 8. Estimating cycle times (min./turn).

SYSTEM PARAMETERS:

Description:	Madill 009 stump rigged for highlead
Slope:	75%, favorable yarding
Terrain:	class 3
Yarding distance:	average[1] = 145 m, maximum = 290 m
Turn size:	average = 3 pieces, 2.46 m^3
Decking method:	mixed cold decking and loading hot.
Mechanical delays > 30 min.:	2.5% of scheduled time

CALCULATIONS:

OUTHAUL	=.205181 +.002887*(145) -.001002*(-75) -.026911*(3) = .618213
CHOKE	= 3.168127 +.147777*(2.46) = 3.531658
INHAUL	=.334184 +.000029*(28033) -.001463*(75) +.083235*(2.46) = 1.24225
UNHOOK	= .670761 +.036156*(2.46) = .759705
DECK	= .485242
MOVE	= .432159
DELAY	= .572639
Total time	= (.618213 + 3.531658 + 1.24225 + .759705 + .485242 + .432159 + .572639) / (1 - .025) = 7.837811

[1] Assuming uniform distribution of pieces, average distance is calculated as: ($MAXD^3$ - $MIND^3$) / 3*(MAXD - MIND), for second order equations in distance, where MAXD and MIND are maximum and minimum distance yarded respectively.

should be compared to descriptions for the strata defined, and an appropriate model or mean time chosen for each element of the work cycle. Next, the values for the predictor variables needed for the various equations must be determined. Third, total cycle time can be computed as the sum of the values for the elements adjusted for mechanical and operational delays in excess of 30 minutes. Alternatively, the user may provide unique values for MOVE and DELAY from other sources. An example of the computations is shown in Table 8.

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