

Harvester-Cable Yarder System Evaluation on Slopes - a Central Euro- pean Study in Thinning Operations

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Abstract

Innovative locomotion technology makes it possible to apply harvester systems in thinning operations on steep slopes. Converting and bunching by harvester will probably improve productivity of the following cable yarder system. The study aims to investigate the interface effect between harvester and cable-yarder. An observational study in first commercial thinning operations in a forest company in the eastern Austrian Alps was carried out. A Skogsjan 687 harvester was used for felling, processing, and bunching. Extraction was done by a Syncrofalke yarder using automatic carriage control.

The investigation results in two main findings: (1) bunching by harvester increases cable yarding by about 25%, and (2) bringing a second chokerman into action improves yarding productivity in the order of the prebunching effect. Further research needs to refine bunching strategy. The results encourage application of harvester technology in thinning operations on slopes.

Key Words: Steep terrain logging, harvester-cable-yarder interface, Skogsjan, Syncrofalke yarder, bunching, productivity study.

Introduction

Harvesting timber on steep slopes is a difficult operation requiring special technology. While the harvester-forwarder system represents the state-of-the-art in trafficable terrain, log extraction on steep slopes has to be achieved by cable or helicopter yarding. Most of the forests of the Central European Alps have been managed for the last two centuries or even longer. Silvicultural treatment therefore requires much selective logging during thinning operations.

Availability of new locomotion technology (self-levelling wheeled platforms, legged platforms) will make it possible to apply harvesters even on slopes. Harvesters do not only improve efficiency, they will influence the following cable yarder productivity by concentrating the logs into bunches. This so-called *bunching effect* is not a new idea. KELLER (1979) and KELLOG (1976) investigated it

more than 20 years ago. Technical innovation has been leading to sophisticated cable yarding and harvester systems in the meantime. One problem in harvesting system design is to put components together optimizing the relevant interfaces. The investigation aims to quantify the effects of different prebunching strategies on the productivity of a cable yarder system.

First an experimental layout is developed, then data are analyzed by statistical methods. The results indicate the need for future investigations and encourage the application of combined harvester-cable yarder systems on steep slopes.

Methodology

Subject Matter Model

In forest operations a huge amount of productivity studies are available. In all such studies the mean volume per piece is the main source of variation. In most cases the relationship between the productivity and the mean volume per piece is not linear (HÄBERLE 1984). In cable yarder operations productivity decreases with increasing yarding distance. In the study the following productivity hypothesis was used:

$$prod_{yard} = f(pvol^e, dist, side, pieces, BUNCH, CHOK, UP)$$

where	$prod_{yard}$	=	system productivity
	$pvol$	=	mean volume per log
	e	=	exponent (curvature)
	$dist$	=	yarding distance
	$side$	=	lateral yarding distance
	$pieces$	=	number of logs per load
	$BUNCH$	=	bunching strategy
	$CHOK$	=	choker setting strategy
	UP	=	direction of yarding

The productivity hypothesis is limited to those effects that probably have the biggest influence and that may be measured or evaluated easily.

Study Layout

To analyze the effects of bunching and choker setting treatment strategies were defined (Table 1).

Tab. 1: *Treatment strategies*

Factor	Level	Treatment Strategy
BUNCH (bunching strategy)	0	no bunching, logs are distributed randomly in the cutting area
	+	normal bunches prepared by harvester
	++	large bunches prepared by harvester
CHOK (choker setting strategy)	1	one chokersetter
	2	two chokersettors

A factorial layout was utilized to investigate the productivity hypothesis. Using the design factors „bunching strategy“ and „choker setting strategy“ a 3x2 - design was used to classify available harvester / cable yarder operations. The layout of cable corridors is presented in table 2. The study layout is unbalanced what is not unusual in productivity studies because the variation of factors is limited under real conditions.

Tab. 2: *Study Layout*

BUNCH	CHOK	cable corridor
0	1	5
0	2	6
+	1	4
+	2	1,3
++	1	-
++	2	2

Study Object

The test area is located in the eastern parts of the Austrian Alps. A small area of forest within the property of the Mayr-Melnhof company served for

Tab. 3: *Variable Definition for Data Sampling.*

<i>response</i>	cycle	total time for one yarding cycle	minutes
	loadvol	total load volume for each yarding cycle	cubic meters u.b.
	prod _{yard}	(loadvol/cycle)*60	m ³ per PSH ¹
<i>factor</i>	BUNCH	bunching strategy; factor containing three levels: (0) no bunching, (+) harvester bunching, (++) improved harvester bunching	3 levels
	CHOK	chokersetters; factor of two levels: (0) one person, (+) two persons.	2 levels
	UP	direction of yarding; factor of two levels: (+) uphill, (0) downhill.	2 levels
<i>covariate</i>	BLOCK	identification of yarding corridors	6 levels
	pvol	mean volume per piece per load	cubic meters u.b.
	pieces	number of logs per load	number
	dist	yarding distance per cycle; chord distance between landing and clamping position of the carriage during lateral yarding.	meters
	side	lateral yarding distance per cycle; distance between skyline and timber bundle to yard	meters

the investigations.

The forest consists almost exclusively of Norway Spruce (*Picea abies*) with an average diameter at breast height of 21 to 25 centimeters. The average age of the stands is around 75 years. Stand density is characterized by 900 stems per hectare with a basal area of 41 square meters per hectare. The silvicultural treatment was a first commercial thinning operation with an average yield of 120 cubic meters per hectare. About 450 stems per hectare had to be removed corresponding a reduction of the basal stand area 44 per cent.

Six cable corridors were studied according to the experimental layout (Table 2). The length of each corridor was between 120 to 140 meters, and the terrain had a slope angle of 15 to 25 per cent with smooth and firm ground. The corridors were marked out before the arrival of the harvester and the loggers.

A Skogsjan 687XL harvester felled, processed and bunched the trees to be extracted. Experienced loggers did the same work motor-manually in the corresponding corridor. A medium sized truck-mounted cable yarder (Austrian manufactured „Synchrofalke“) accomplished the extracting operation. The „Synchrofalke“ cable yarder consists of a 10 meter tower, hydrostatically driven winches and a computerized carriage control system. This control system is capable of moving the carriage automatically back to the previous load building location in the stand. The choker setter

has a radio control device to operate the yarder during the lateral yarding task. The control abilities of the yarder make it possible to operate the whole yarding system with only two crewmen, the first operating the yarder and swinging the logs at the landing using the integrated crane-mounted grapple, the second setting chokers and operating the lateral yarding process. In some of the corridors two chokermen accomplished the load-building task in the stand.

Data Sampling

For each of the six study replications the response variables, the factors and the covariates (Table 3) had to be gathered on the yarding-cycle level. There were 225 yarding cycles investigated. Three people recorded the time elements using hand-held computers. Volume information includes the volume of the total load and the number of logs. The mid-diameter and the length of each log allowed the log volume to be calculated. Each log relates to one load cycle which allows the calculation of the response variable *loadvol* and the covariates *pvol* and *pieces* (Table 3). Yarding covariates (*dist*, *side*) are available for each yarding cycle. Yarding distance was marked along each cable road before the beginning of the operation. The lateral yarding distance was rounded to the nearest five meters.

¹ PSH Productive System Hour

Statistical Analysis

In the analysis factors were included using coding procedures that transformed categorical data into metric variables. All the analysis was done using 0/1-coding (treatment coding). Analysis was carried out by regression techniques applying the following strategy:

- fit a model with all covariates and factors of table 3;
- select a series of sub-models by dropping variables that are not significant;
- choose two-way interactions of the sub-models;
- evaluate non-linearity of the covariates.

Fitting the parameters of regression models was done with linear model fitting procedures of S-Plus (see VENABLES AND RIPLEY, 1994). Non-linearity of the covariate *pvol* was evaluated using power transformation. The most appropriate transformation was derived iteratively by looking for the exponent that produced maximal partial variance. One problem that may occur in unbalanced designs is the occurrence of model singularities. The analysis was therefore done interactively to find the model that best explains the influence of factors and covariates and that is as simple as possible.

Results and Discussion

Characteristics of the Yarding Cycles

Table 4 shows the characteristics of the investigated yarding cycles. 10 to 25 cycles per productive system hour PSH were run by the cable yarding system. Another interesting finding is the number of logs per cycle. An average of 7.7 pieces is an extremely high value, because the number of pieces is usually lower than five. The extremely small volume per log and the pre-bunching are possible explanations for this finding.

Tab. 4: Variability of the response variables and the covariates

variable	mean	0.05 quantile	0.95 quantile
cycle	4.0 min	2.5 min	5.8 min

loadvol	0.90 m ³	0.38 m ³	1.46 m ³
dist	61 m	10 m	130 m
side	9.6 m	0 m	25 m
pieces	7.7	4	14
pvol	0.13 m ³	0.06 m ³	0.24 m ³

Productivity Model

Statistical analysis resulted in productivity model [1].

$$\begin{aligned}
 [1] \text{ prod}_{\text{yard}} = & -3.51 + 14.89 \cdot \text{pvol}^{0.6} - 1.12 \cdot \text{pieces} \\
 & - 0.045 \cdot \text{dist} - 0.12 \cdot \text{side} \\
 & + 10.48 \cdot (\text{pvol}^{0.6} \cdot \text{pieces}) \\
 & + 2.96 \cdot \text{BUNCH1} + 2.48 \cdot \text{BUNCH2} \\
 & + 2.67 \cdot \text{CHOK} + 5.15 \cdot \text{UP}
 \end{aligned}$$

where	<i>prod_{yard}</i>	=	system productivity
	<i>pvol</i>	=	mean volume per log
	<i>dist</i>	=	yarding distance
	<i>side</i>	=	lateral yarding distance
	<i>pieces</i>	=	number of logs per load
	<i>BUNCH</i>	=	bunching strategy
	<i>CHOK</i>	=	choker setting strategy
	<i>UP</i>	=	direction of yarding

All two-level factors of Table 1 take on the value of 0 for the „0“-level, and the value of 1 for the „+“-level. *BUNCH* is a three-level factor that is represented by two binary variables *BUNCH1* and *BUNCH2*. For the „-“-level of *BUNCH* both, *BUNCH1* and *BUNCH2* take on the value of 0. The „+“-level is represented by *BUNCH1*=1, and *BUNCH2*=0 whereas *BUNCH1*=0, and *BUNCH2*=1 characterizes the „++“-level.

Häberle (1984) proposed to transform $pvol$ by raising it to the power of a variable e to reproduce the curvature phenomenon of productivity functions. Variation of the exponent e from 0.3 to 1.3 results in minimal residual sums of square at a value of e equal to 0.6. All further analysis will therefore be done raising $pvol$ to the power of 0.6. Model [1] has a standard error of 3.6 and an R squared of 0.74 which is quite satisfactory for productivity studies.

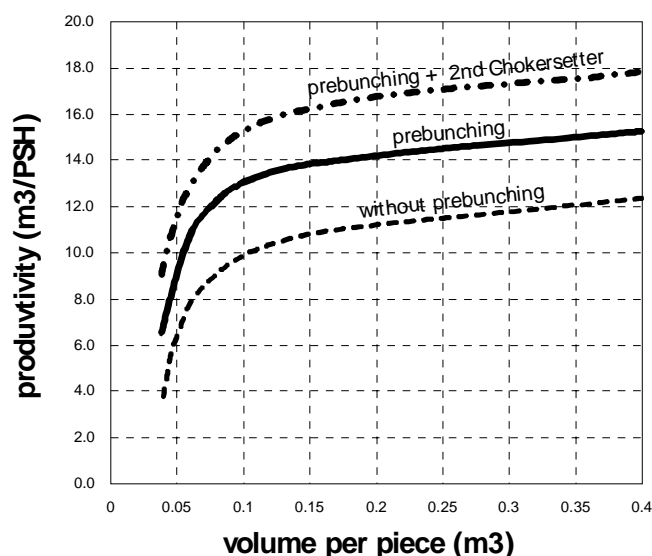


Fig. 1: Productivity of the Cable Yarder System depending on volume per piece and bunching strategy

Figure 1 shows the productivity for three treatment strategies. The main effects yarding distance (*dist*), lateral yarding distance (*side*) and load volume (*loadvol*) were set to the mean conditions of the study area (see Table 4). Under similar conditions bunching improves cable yarder productivity by about 27%. Sensitivity analysis indicates that the degree of improvement increases with smaller piece volume to a maximum of about 45%, whereas larger piece volume decreases the improvement only slightly.

The influence of improved harvester bunching (,,+“-level of the *BUNCH* factor) is of the same order as normal harvester bunching (,,+“-level of

the *BUNCH* factor). The fitted coefficients have standard errors of 0.7 and 0.9 respectively which is why the difference is within randomness.

The influence of a second chokersetter (*CHOK*) is significant. It improves the yarder productivity by about 2.7 cubic meters per productive system hour. The effect is similar to the bunching effect. Combining bunching and using two chokersetters results in the highest system productivity (Figure 1). Uphill yarding (*UP*) increases the yarder productivity by about five cubic meters per productive system hour. Estimation of the uphill yarding coefficient is based on only one replication and has to be used with care.

Analysis of variance of model [1] shows that 75% of the total variance may be explained by the factor and covariate effects. The covariates *pvol*, *pieces* and their interaction explain 65% of the variance whereas the factors *BUNCH*, *CHOK* and *UP* only account for about 5%.

Conclusions

The study results in the following findings:

- A fitted linear model shows that bunching by harvester improves system productivity by about 25 per cent.
- Approximately the same increase of productivity results by bringing two chokermen into action.
- Grading of the bunching strategies by three levels of factor *BUNCH* did not result in definitive findings.

Previous studies about the bunching effect on cable yarding systems did not give definite results (KELLOG, 1976; KELLER, 1979). Other authors investigated skidder extraction (BILLER AND BAUMGRAS, 1986; STOKES AND LANFORD, 1985) while LEDOUX AND BUTLER (1982) carried out a simulation analysis, concluding that bunching small diameter logs into skyline corridors can be a feasible alternative for thinning operations. BILLER AND BAUMGRAS (1986) defined three bunching strategies: (1) bunch volume is smaller than mean load volume, (2) average bunch volume is approximately equal to the mean load vol-

ume, and (3) average bunch volume is greater than the mean load volume. They found that strategies (1) and (2) resulted in similar productivity; one and a half times higher than applying non-prebunched baseline conditions. Strategy (3) effected a 50 per cent increase of the mean load volume and approximately doubled skidder production. The investigation leads one to suppose that the „+“ as well as the „++“ level of the *BUNCH* factor stand for bunch volumes is equal for smaller than the mean load volume.

The present study is the first investigating the interface effect between a single grip harvester and a cable yarding system in thinning operations. The results are promising for the development of steep slope harvesters based on different locomotion principles (wheeled, tracked, legged).

The findings of the study need to be refined in the future. Bunching strategies should be stated more precisely following the findings of BILLER AND BAUMGRAS (1986). Bunch volumes considerably above the mean load volume seem to be most promising to improve cable yarder productivity.

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