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Productivity Models for Cable Yarding in Alpine Forests

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Abstract

The authors tested the same modern mid-size tower yarder for uphill and downhill extraction. The yarding machine is a popular commercial model offering state-of-the-art yarding technology, including telescoping tower and full hydrostatic transmission. The machine was studied while harvesting selective patch cuts (gap cutting) in similar even-aged Norway Spruce stands, extracting logs between 3 and 6 metres long. The operation was carried out by the same experienced 3-man crew. Productivity ranged between 8.5 and 10 m^3/h, including all delays, but excluding set-up and dismantle time. A set of regression equations for estimating machine productivity were calculated as a function of the main work conditions, such as yarding distance, lateral extraction distance, mean log size and number of logs per turn. Machine utilization was about 60%, which is consistent with previous studies. In general, cable logging is more complex and expensive than ground-based logging, which places steep terrain forestry at a general disadvantage in terms of pure harvesting cost. However, modern cable yarding technology can reduce this gap, and productivity models can assist users in refining their work technique, so as to maximize the productive potential of their machines.

Keywords: Yarding, Logging, Mountain, Time Study, Productivity

1. Introduction

Forests cover 40% of the Alpine landscape and have an important role in supporting the alpine economy (Onida, 2009). Alpine forests also have a protective function as they prevent soil erosion and shield settlements from avalanches and rock fall (Dorren et al., 2004). The need to guarantee both cost-effective wood production and careful hydro-geologic protection makes alpine forestry especially complex. Continuous-cover forestry is popular because it offers a good compromise between these two vital functions. However, continuous-cover forestry may reduce removal intensity and increase harvesting cost (Mason et al., 1999). Furthermore, the typical access constraints of the Alpine territory often prevent the introduction of modern harvester-forwarder technology (Zambelli et al., 2012), which is a main solution to cost containment in the face of increasing fuel and labor cost (Spinelli et al., 2011). As a consequence silviculture treatment is often delayed and results in a skewed age distribution (Binder et al., 2004). That contributes to the high vulnerability of Alpine forests to the effects of climate change (Seidl et al., 2011). Therefore, it is crucial to optimize forest operations in order to guarantee timely regeneration and maximize resiliency.

When slope gradient exceeds 40 %, ground-based harvesting technology cannot offer good results and cable logging remains the main solution. Cable yarding is the most common steep slope harvesting techniques world wide (Bont and Heinimann, 2012). Cable yarding is especially popular in the Alps, and most modern yarder developments originate there. In 2012, there were over 350 cable logging contractors in alpine Italy alone (Spinelli et al., 2013). On steep terrain, cable yarding is the cost-effective alternative to building an extensive network of skidding trails and results in a much lower site impact compared to ground-based logging (Spinelli et al., 2010a). On the other hand, cable yarding is inherently expensive because it is normally deployed on difficult sites. For this reason, cable logging offers lower profit margins compared to ground-based logging. This justifies a stronger optimization effort, supported by a deeper knowledge of technical cost and market rates.

The goal of this study was therefore to develop a productivity model for cable yarding, conducted with a modern medium-size tower yarder under the conditions of close-to-nature forestry.

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2. Materials and methods

2.1 Site description

The study focused on the Valentini V600 M3 medium-size tower yarder, among the most widespread in the Italian Alps. The main characteristics of the machine are described in table 1. The Valentini V600 M3 is a trailer-mounted yarder with a 12 m telescoping tower. The machine is powered by a 116 kW engine, through a fully hydrostatic transmission. The transmission acts on three main drums, containing the skyline, the mainline and the haulback line. The maximum length of the skyline is 1000 m for a 20 mm diameter swaged cable. The three-drum configuration allows use for uphill and downhill yarding, with the winch positioned at the upper or the lower end of the line. For this reason, the test covered both main configurations, and namely: uphill yarding with the yarder positioned at the upper end of the line (2-cable configuration) and downhill yarding with yarder positioned at the lower end of the line (3-cable configuration). In both tests, the same machine and teams were used, including the same Steufer HK2002 3-ton self-clamping carriage.

The study was conducted in two Norway-spruce (*Picea abies* Karst.) forests in the Eastern Alps, in the Province of Trento. Stand and operation characteristics are shown in Table 1. The stands selected for the study are representative of the two main cases described above: stand one was below the main trail and the wood was yarded uphill to the tower yarder that sat on the trail at the upper edge of the stand; on the contrary, stand two was located uphill from the main access trail, so that the tower yarder was installed on the trail at the lower edge of the stand and wood was yarded downhill.

Overall, the study covered 67 work hours during which 382 trees or 628 m^3 of wood were yarded. At both sites, trees were felled, delimbed and cross-cut into final assortments before yarding, using chainsaws. Log length varied between 3 and 6 m. The team consisted of three people, of which one acted as winch operator and chaser, and two as choker-setters at the loading site. On longer later distances an additional choker-setter was employed for helping with the cable. The operators performing the work were the same in both tests. All operators had at least 5 years of experience with cable yarding and they were all 35-45 years of age range. No attempt was made to normalize individual performances by means of productivity ratings (Scott, 1973), recognizing that all kinds of normalization or corrections can introduce new sources of errors and uncontrolled variation in the data material (Gullberg, 1995). The Authors believe that the selected operators were representative of the professional, expert and motivated workforce needed for the efficient operation of modern equipment.

The authors carried out a time-motion study, designed to evaluate yarder productivity and to identify those variables that are most likely to affect it, especially extraction distance, lateral yarding distance and payload size (Bergstrand, 1991). Each yarding cycle was stop watched individually using Husky Hunter hand-held field computers running the dedicated Siwork3 time study software (Kofman, 1995). Productive time was separated from delay time (Magagnotti et al., 2013). Yarding distances were determined with a laser range-finder. No correction was made for slope gradient, so that these distances represent the actual paths covered by the carriages, and not the linear topographic distances. Load size was determined by measuring the length at the diameter at mid-length of all logs in each load.

Data from individual cycle observations were analyzed with the regression technique in order to calculate meaningful relationships between productive time consumption and work conditions, such as yarding distance and load size (SAS, 1999).

Table 1. Characteristics of the test sites

Site	1	2
Place Name	San Martino	Paneveggio
Province	Trento	Trento
Elevation (m asl)	1570	1620
Species	Norway spruce	
Stand type	Even-aged forest	
Operation	Gap cutting	
Removal (#)	252	130
Removal (m^3)	381	247
Avg. Tree(m^3)	1.51	1.9
Avg. DBH (cm)	40	42
Slope gradient (%)	62	60
Extraction (direction)	Uphill	Downhill

3. Results and Discussion

3.1 General

Table 2 shows the overall results of the study. The two settings were quite similar, but one of the main differences was that the data collected from the Paneveggio site was just in a small part of the extraction corridor. The average yarding distance was therefore quite long (268 m) and the data range quite narrow- all between 170 and 320 meters. Data from San Martino spanned from 0-220 meters (average yarding distance of 130 m).

3.2 Work time and delays

As can be expected with the longer average yarding distance, both Carriage.In and Carriage.Out took longer on average for the Paneveggio site. However loading also took about to a minute longer, which can be explained by the extra yarding distance, i.e. 24m at Paneveggio versus 16 m at San Martino (Figure 1, 2)

The total study time was too short to have any meaningful analyses of the delay components. They are presented here for completion. 44% and 30% were the respective total delays, whereby the larger value for San Martino was primarily due to the “Drive” component.

Table 2. Descriptive statistics (mean and standard deviation) related to soil physical and chemical properties

Site	1	2
Place Name	San Martino	Paneveggio
Extraction (direction)	Uphill	Downhill
Span Length (m)	350	340
Total Work-Only Time (h)	21.3	20.3
Total Delay time (h)	16.7	8.7
Total Volume Extracted (m^3)	381	247
Number of cycles (#)	171	137
Num Logs (#)	1077	686
# Logs per Turn	6.2	4.9
Piece Size (m^3)	0.40	0.39
Yarding Distance (m)	130	268
Lateral Extraction Distance (m)	16	24
Cycle Time (min)	7.4	8.9
Work-Time Productivity (m^3/h)	17.8	12.1
TotalTime Productivity (m^3/h)	10.0	8.5

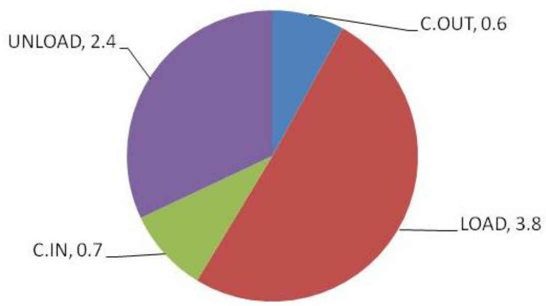

Figure 1. Breakdown of Work Only cycle time SAN MARTINO in minutes (Average cycle time was 7.4 minutes).

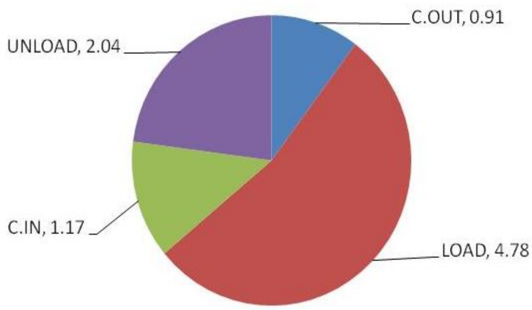

Figure 2. Breakdown of Work Only cycle time Paneveggio in minutes (Average cycle time was 8.9 minutes).

3.3 Carriage Movement

Carriage.Out was very consistent with distance - showing good operator experience. Extraction from the back end of the setting showed to be difficult with the largest variation in Carriage.In time. On average, Carriage.In was only 20% longer than Carriage.Out, indicating Smooth extraction. High R^2 was for both data sets (Figure 3).

The major problem was with the Paneveggio data set, because data was captured for small segments of the extraction corridor, since the harvest areas were concentrated in patches. However, Carriage.Out was quite consistent with distance – showing reasonable operator experience. Extraction from at all points showed to be difficult with large variation in Carriage.In time. On average, Carriage.In was about 25% longer than Carriage.Out. High R^2 was only for Carriage.Out (Figure 4).

3.4 Loading and unloading

There was almost no correlation between time to load or unload a turn and the turn volume. This indicates that the choker-setters where limited to the available logs in the vicinity and did not seem to be able to build optimum size turns. This presents perhaps the greatest opportunity for improvement, as maximizing turn volume optimizes productivity. Limitations can occur in Small piece-size when the number of chokers limit the payload.

3.5 Productivity functions

The following productivity functions were established using a stepwise model with all the variables. As expected, the yarding distance data for Paneveggio was not spread enough for it to become a significant factor in the final model, with Lateral Yarding Distance and Average Piece Size dominating the function (Equation 1, 2).

Combining both data sets and adding a block for uphill and downhill yarding, and evaluating using statistics showed there was almost no difference (f=0.968) for this block factor. When forced, the coefficient is just 0.06 – that is for this data set Downhill yarding was just 0.06 m^3/hr faster (not statistically significant).

From the combined data set the following productivity function we can also build a productivity function. Only DIST, LAT and AVEPIECE was used, as number of pieces is not a useful predictor variable. Knowing that average piece size usually affect productivity at decreasing rate, various transformation were tested, and AVEPIECE ^ 0.6 (=AVEP0.6) yielded the strongest model (Equation 3). Graphically this would look like the graph in Figure 5.

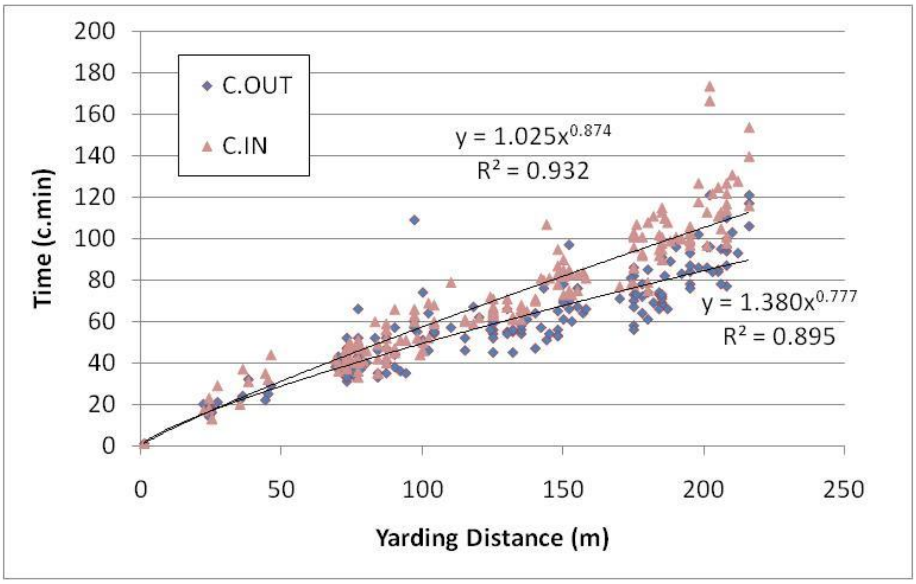

Figure 3. Plot of yarding distance (m) with time (c.min) for both Carriage Out and Carriage In at San Martino

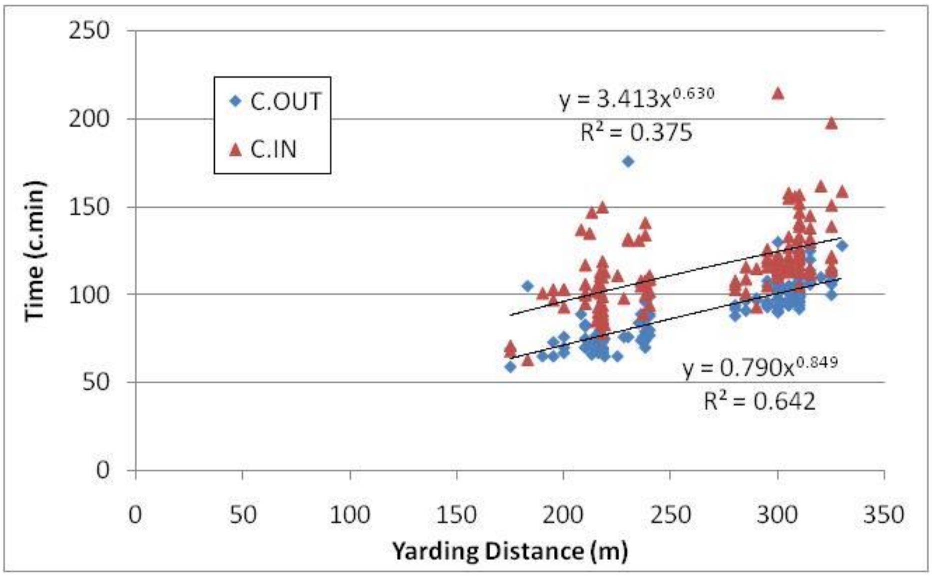

Figure 4. Plot of yarding distance (m) with time (c.min) for both Carriage Out and Carriage In Paneveggio

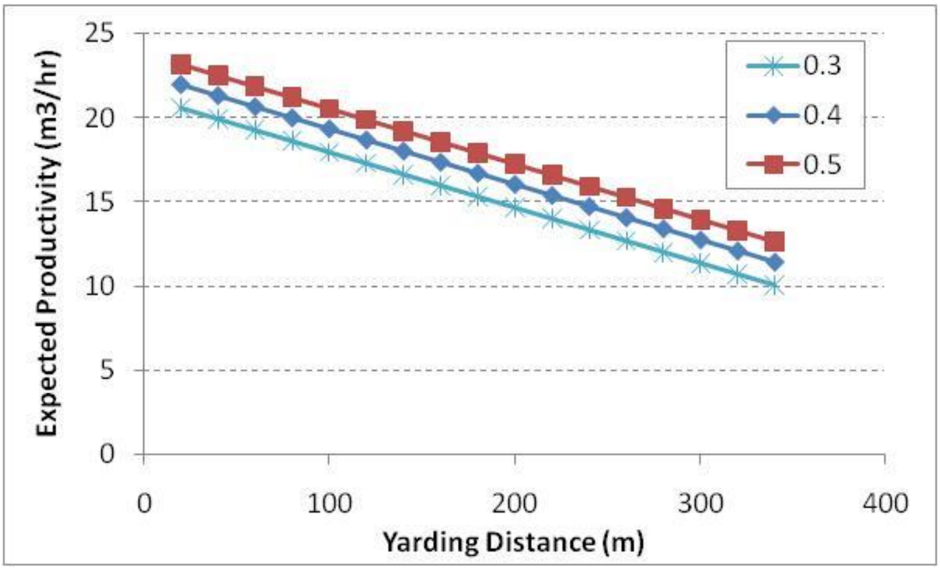

Figure 5. Expected Yarder Productivity (m^3/hr) for the combined San Martino and Paneveggio data sets for three different average piece sizes (assuming an average lateral extraction distance of 20 meters)

San Martino Productivity (m^3/h) =
13.9 – 0.048 x DIST – 0.143 x LAT + 1.11 x NumLogs + 15.28 x AVEPIECE (1)
R^2 = 0.39

Paneveggio Productivity (m^3/h) =
-5.31 – 0.06 x LAT + 1.96 x NUMLOGS + 25.6 x AVEPIECE (2)
R^2 = 0.66

San Martino and Paneveggio combined - Productivity (m^3/h) =
16.05 – 0.033 x DIST – 0.102 x LAT + 14.96 x AVEP0.6 (3)
R^2 = 0.42

whereby
DIST = Yarding distance (m)
LAT = Lateral yarding distance (m)
NUMLOGS = Number of logs per turn (#)
AVEPIECE = Average Piece Size (m^3)

4. Discussion and conclusions

First of all, it is important to stress the preliminary and observational character of the study, which was performed under the conditions of a commercial operation. For this reason, it was impossible to test both configuration under the exact same work conditions, which may explain why the study could not detect any differences between uphill and downhill yarding. Other studies have encountered with the same difficulties, again explained by their observational character. In real practice, operators use the two separate configurations to cope with different conditions, which makes it impossible for a proper scientific comparison. In fact, if the two different configurations are designed for use under different conditions, such comparison would make little sense anyway. Furthermore, much of the time consumption difference between the two yarder configurations can be expected in the set-up and dismantle time, rather than in the yarding proper. This study does not include a recording of set-up and dismantle times, but these can be easily calculated from Stampfer et al. (2005), which clearly reports of longer set-up and dismantle times for the three-cable configuration designed for downhill yarding.

The productivity recorded in this study is over 2 times higher than indicated for the softwood stands of Turkey (Acar et al., 201; Senturk et al., 2007) and about 4 times higher than reported and for the coppice stands of Southern Italy (Zimbalatti and Proto, 2009). Such differences can be explained by the use of a more modern and powerful machine in the first case, which is compounded by a larger tree size in the second case. In fact, the machines used in the quoted Turkish and Southern Italian studies were smaller, simpler and less powerful than the V600 model used in the present study. In particular, the V600 features a fully hydrostatic transmission that confers faster and smoother operation.

On the other hand, the utilization rates determined by our study are about the same as reported by Huyler and LeDoux (1997) and Spinelli et al (2010b) for popular light tower yarder models, but readers must be warned against the limited duration of our study, which did not allow for a conclusive estimate of machine reliability.

In general, cable logging is more complex and expensive than ground-based logging, which places steep terrain forestry at a general disadvantage in terms of pure harvesting cost. However, modern cable yarding technology can reduce this gap, and productivity models can assist users in refining their work technique, so as to maximize the productive potential of their machines.

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