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PRODUCTIVITY AND COSTS OF CABLE YARDING IN GROUP SHELTERWOOD SYSTEM IN DECIDUOUS FORESTS

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Abstract

The aim of the present study was to improve the use and operational efficiency of the truck-mounted tower yarders in deciduous stands and to determine the time, log's volume transported per turn by the yarder, as well as the yarding costs. The study was carried out in the Sredna Gora Mountains, Central Bulgaria, in deciduous stand with species composition of European beech (90 %), European hornbeam (10 %). The mean productivity of truck-mounted tower cable yarder at shift level is close to the maximum for that type (9.12 $m^3 \cdot PMH^{-1}$ and 8.41 $m^3 \cdot SMH^{-1}$). In order to improve the yarder productivity a remote control of the carriage is advisable to be used, also used by the choker-setter. In this way the loaded carriage could wait for the operator before the landing. Another option to reduce choker-setter's fatigue and to decrease the time for lateral outhaul and hook is to use a carriage with mechanical slack-pulling. The gross costs for yarding uphill a whole deciduous tree by the studied tower yarder were calculated at 146.52 € per productive machine hour and 13.02 € per m^3. In the distribution of the gross costs, labour costs (21.44 %) are lower than variable costs (29.86 %) and fixed costs (26.84 %).

The results from the study are useful to integrate the cable yarders in group shelterwood system and to achieve economic and environmental efficiency of timber transportation in deciduous forests in sensitive sites.

Key words: timber harvesting, economic evaluation, Natura 2000, Sredna Gora Mountains.

Introduction

The cable yarding is taking logs from a stump area to a landing using an overhead system of winch-driven cables to which logs are attached with chokers (Stokes et al. 1989). The standing line is a fixed cable that does not move during logging operations; for example, a skyline anchored at both ends. The mobile cable yarders have a tower – steel mast used instead of a spar tree at the landing for cable yarding.

The major advantage of cable-based extraction systems seems to be their independency from many system-influencing factors. Planning and implementation can be done almost anytime and on any terrain (Schweier et al. 2020).

The cable yarding is a good alternative to a ground-based skidding where side slopes are greater than 30 % (LeDoux and Huyler 2000). In general, cable yarding is more complex and expensive than ground-based logging, which places the steep terrain cable yarding operations at a general disadvantage in terms of pure harvesting cost. However, modern cable yarding technology can fill this gap, and productivity models can assist users in refining their work technique, so as to maximize the productive potential of their machines (Spinelli et al. 2015). As the cable yarding is more costly than ground-based systems, this technology requires a multiproduct market and a site with a large volume of quality timber (LeDoux and Huyler 2000), but 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. 2010).

Cable yarding systems are used mainly for uphill yarding due to their much easier and faster rigging. The most common timber harvest unit layouts are parallel or fan-shaped (Peters and LeDoux 1984). Recently, the double-hitch carriages have been developed to allow for full suspension of whole-tree and tree-length material; the double-hitch carriage took longer to load up, but was able to achieve similar productivity through increased inhaul speed, especially for settings with limited deflection, or areas with lower tolerance for soil disturbance (Spinelli et al. 2021).

Interestingly, according to the most researches, it seems that cable yarders operate mainly in coniferous forests. A small amount of studies has been done in deciduous forests – mainly in the Appalachians in the Northeast of United States (LeDoux 1985a,b; Huyler and LeDoux 1997a,b; Visser et al. 2001), Southern Germany (Schweier et al. 2020), Southern Italy (Zimbalatti and Proto 2009, Proto and Zimbalatti 2016), and Turkey (Melemez et al. 2014).

In Bulgaria approximately 60 % of the forests are located in mountainous areas with steep slopes and complex terrain configurations. Despite the share of deciduous tree species in forest territory is 71 %, whereas the share from total growing stock is 55.5 % (EFA 2021) the recent studies on cable yarding in coniferous forests also prevail (Stoilov 2019, Boyadzhiev et al. 2020, Boyadzhiev and Glushkov 2021, Stoilov et al. 2021). Therefore, the study of yarding operations in deciduous forests is important for improving forest management in Bulgarian forest areas.

Currently, in Bulgaria about 40 mobile tower yarders operate, incl. 3 mountain harvesters. Tractor-mounted tower yarders have been widely used in Bulgaria since 1980 in primary timber transportation. Nowadays, many truck-mounted tower yarders have been introduced (Stoilov 2021).

Lateral yarding consists of moving the trees or logs (load) to a bunching point from where the load is partly or entirely lifted off the ground by a cable (mainline) and moved to a landing. Truck-mounted tower cable yarders are driven by hydrostatic transmission.

Both single- and multi-span layouts are used for tower yarders. For single-span layouts, a crew of 2-, 3-, and 4-members can be used when using solely a yarder and a 3- and 4-member crew when using both a yarder and skidder (Kellogg 1981, Kellogg and Olsen 1984).

According to Huyler and Ledoux (1997b) the yarding delays for operational, mechanical, and non-productive time accounted for approximately 35 % of the total cycle time on steep slopes in the Northeast US. Huyler and Ledoux (1997b) also proposed that delays should be factored to separate the delay-free time to be able to give an estimate of the total cycle time. The average delay-free-cycle time was 5.72 minutes (Huyler and LeDoux 1997a). The relevant variables used in the time prediction equation were the yarding distance, lateral yarding distance, volume per turn and stem volume.

According to Dimitrov (2012), to increase the productivity of tractor-mounted tower yarder operated in European beech (*Fagus sylvatica* L.) stands located in the Ograzhden Mountains (Southwest Bulgaria), operational times for lateral outhaul (28 %), inhaul (21 %), spare and delays of workers (16 %) and unhook (13 %) should be minimized. He also estimated that the mean productivity of the studied yarder of 3.22 $m^3 \cdot h^{-1}$ for 33 m lateral yarding and 230 m outhaul could be defined as moderate. The results are comparable with those of the studies carried out in coniferous stands of Northeast Turkey – 6.6 $m^3 \cdot h^{-1}$, 5.5 $m^3 \cdot h^{-1}$, and 4.9 $m^3 \cdot h^{-1}$, respectively for inhaul distances of 100, 200, and 250 m (Senturk et al. 2007).

Production rates observed by Zimbalatti and Proto (2009) during firewood yarding operations in two Turkey oak (*Quercus cerris* L.) stands in Calabria, Italy, were lower – mean load volume of 0.75 and 0.54 m^3, and productivity of 2.38 and 3.21 $m^3 \cdot h^{-1}$, respectively for coppice and high forest. According to Melemez et al. (2014) the extraction by skyline was determined to be the most efficient extraction method, but the slope of the terrain needs to be greater than 50 % to use this method.

Most operations will be economically efficient when taking place in a high-yield stand and when all factors affecting costs of operations have been considered carefully (LeDoux 1985a).

The production costs of the two systems in flat terrains analysed by Schweier et al. (2020) had a comparable range, between 32.5 ±5.9 €·m^{-3} (Koller K507) and 36.2 ±7.5 €·m^{-3} (Valentini V400) (both including processing at roadside). However, the K507 system was used to process timber of significantly larger dimensions, which was more cost-efficient.

The aim of the present study was to improve the use and operational efficiency of the truck-mounted tower yarders in deciduous stands and to determine the time, log's volume transported per unit by the yarder, as well as the yarding costs. The knowledge of these parameters is useful to integrate the work of cable yarders in order to achieve economic and environmental efficiency of timber harvesting in deciduous forests included in Natura 2000 network.

Material and Methods

Description of the site and yarding setup

The study was carried out in the Sredna Gora Mountains (42°34'58.53″ N – 24°24'14.96″ E) around the city of Koprivshtitsa, Sofia Province, Central Bulgaria. Stand and operation characteristics are shown in Table 1.

The studied stand is a part of Natura 2000 network with function codes BG 0002054 and BG 0001389, listed respectively under the Birds Directive and the Habitats Directive. The type of habitat is 9130 Asperulo-Fagetum beech forests. The species composition includes European beech (*Fagus sylvatica* L.) and European hornbeam (*Caprinus betulus* L.).

Table 1. Characteristics of the test site.

Parameter	Characteristics
Place Name	Stara Baraka, sub-compartment 9067-b
Elevation	1000 m asl
Function	Natura 2000: BG 0001389, BG 0002054
Species composition	European beech – 90 %, European hornbeam – 10 %
Stand age	110 years
Stand type	Natural high forest
Total area	23.2 ha
Relative stocking	0.8
Sylvicultural system	Group shelterwood, removal intensity 25 %
Average tree height	22 m
Average DBH of tree	34 cm
Average slope gradient	24° (45 %)
Growing stock	9120 m^3 (393 $m^3 \cdot ha^{-1}$)
Allowable cut	2080 m^3 (90 $m^3 \cdot ha^{-1}$)
Extraction direction	Uphill
Length of line	Site A: 280 m; site B: 165 m; site C: 195 m
Average lateral outhaul	14.4 m

Three fan-shaped skyline corridors with average skyline length of 300 m were opened on terrain slopes at about 16° (29 %), 20° (36 %), and 24° (45 %). Field observations were carried out on 30 work cycles (turns) at each corridor. Extraction direction was uphill and trees were manually felled and single-span layout was implemented each time.

Cable yarder unit

The study was focused on a Koller K501 truck-mounted tower yarder (Table 2). The work team consisted of three people, of which one was the winch and crane operator, the second one unhooks, delimbs and crosscuts the trees, and the third one was choker-setter at the loading site. The work team had at least 5 years of experience with cable yarding and they were all 30–55-years-old.

The tested mobile tower yarder is designed for uphill logging, mounted on a truck with pressure air-brakes. The K501 is a powerful yarder, principally used for selective cuts and for regenerative harvesting operations using a carriage SKA 2.5 (Koller Forsttechnik GmbH, Schwoich, Austria) for payloads up to 2.5 t. The mass (9800 kg) was distributed on the rear axles of a Mercedes-Benz truck with special reinforced frames. The logs were yarded laterally to the carriage using the power of the yarder's mainline winch and active skyline clamps (Proto and Zimbalatti 2016).

Productivity study and costs

A detailed time and motion study was conducted to estimate the duration of work elements and productivity of the cable yarders in the given conditions. A yarding work cycle was assumed to be composed of repetitive elements (Kellogg et al. 1996, Olsen et al. 1998, Spinelli et al. 2015, Proto et al. 2016, Munteanu et al. 2017). In this study, six work elements were sepa-

Table 2. Technical data of the studied Koller K501 cable yarder.

Parameter	Value
Skyline capacity 600 m, ø24 mm	120 kN (tension section)
Mainline 600 m, ø14 mm	43 kN (average drum)
Guylines	4×75 m, ø16 mm / 2×15 m (extension)
Foldable telescopic tower, height	13.5 m
Power station	Autonomous engine and hydrostatic transmission
Engine power of the autonomous engine	250 kW (340 hp)
Brakes of skyline	Manually actuated band brake
Brakes of mainline	Hydraulically actuated band brake
Operation	Hydro-mechanical / electro-hydraulic single lever operation with dead-man´s control
Carriage	Koller SKA-2.5 manual slack-pulling carriage
Chooker system	Bardon choker
Lifting moment of the crane	270 kNm
Carrier	6×4 Mercedes-Benz truck

rated and taken into account in order to estimate the work cycle time (Huyler and LeDoux 1997b); they were similar to those described by Proto and Zimbalatti (2016):

- Carriage outhaul (CO) begins when the operator is ready to move the empty carriage from the landing out to the stump and ends when the choker-setter touches the chokers;

- Lateral outhaul and hook (LOH) begins at the end of carriage outhaul and ends when the choker-setter has completed hooking the chokers and signals to begin yarding;

- Lateral inhaul (LI) begins at the end of hook up and ends when the turn is pulled up to the carriage and the carriage begins to move up the corridor;

- Carriage inhaul (CI) begins at the end of lateral inhaul and ends when the load has reached the deck where it can be directly unhooked at the landing;

- Unhook (U) begins at the end of carriage inhaul and ends when the chokers have returned to the carriage;

- Delay time (D) includes the rest, personal delays, organizational delays, service, and repair.

The time-motion study was designed to evaluate duration of work elements and yarder productivity and to identify those variables that are most likely to affect it. Each yarding cycle was individually measured by a stopwatch and the productive time was separated from delay time. The yarding distances and terrain slopes were measured with a professional laser range-finder with clinometer. The load volume per turn was determined by measuring the length and the mid-length diameter of all logs from each load.

The machine costs were calculated using the COST model (Ackerman et al. 2014). In order to calculate the production cost for 1 m^3 of timber, the cost analysis employed the following parameters: the number of operators, the hourly cost of an operator, the hourly cost of machines, the volume of extracted timber and the productive machine hours (excluding all delay times). The machine costs per hour were reported both as productive machine hours and scheduled machine hours. The purchase prices and operator wages required by the cost calculations were obtained from catalogues and accounting records (Proto et al. 2016). The labour cost was set to 37.87 €·SMH^{-1} inclusive of indirect salary costs. The diesel fuel consumption was measured by evaluating the volume of fuel used to fill the fuel tank to the brim and recording the amount of fuel used during that day. A salvage value of 10 % of the purchase price was assumed and the Value Added Tax (VAT) was excluded. Cost calculations were based on the assumption that companies worked for 150 working days in the year and a depreciation period of 10 years. For extraction work this amounts to 130–150 working days per year (20–21 working days per month), at an average of 6–7 scheduled working hours per day (assuming one to two hours spent on lunch, rest and other breaks). This yielded annual working times of 910–1050 SMHs with a 70 % use coefficient (Spinelli and Magagnotti 2011, Spinelli et al. 2014, Proto et al. 2018).

Data analysis

A regression analysis was performed on the experimental data in order to develop prediction equations for estimating the work cycle time and productivity. The independent variables used in the modelling approach included yarding distance L, lateral yarding distance l, load volume per cycle V, terrain slope angle i, and the load's number of trees n. The descriptive statistics of the variables were computed and a stepwise backward regression procedure was used to model the variability of yarding cycle time and productivity as a function of independent variables.

The confidence level used for regression analysis was 95 % (α = 0.05) and the assumed probability $p < 0.05$. Independent variables are significant at $p < 0.05$, i.e. strong presumption against neutral hypothesis. The experimental data was processed by Statistica 8 (StatSoft Inc., Tulsa, OK, USA) software.

Results and Discussion

The summary of experimental data from 90 cycles for each of the selected variables used in the cycle time and production equations is shown in Table 3.

Duration of work cycle elements

The greatest portion of cycle time (Fig. 1) was dedicated to the carriage inhaul (37 % and 29 % respectively, excluding and including delays) and it was most probably related to the low inhaul velocity of carriage with a load. Unhook accounted for the smallest share (10 % and 8 % respectively, excluding and including delays). Lateral inhaul accounted for the second highest share (29 % and 23 % respectively, excluding and including delays), followed by lateral outhaul and hook (13 % and 10 % respectively, excluding and including delays), and carriage outhaul (11 % and 9 % respectively, excluding and including delays). Operational and mechanical delays accounted respectively for 16 % and 5 % of the total cycle time of the studied cable yarder.

Operations related to the lateral yarding (the lateral pull of the main line, the chokers hooking, and the extraction of the load to carriage) occupy 42 % within work cycle time including delays, and 53 % within delay-free work cycle. In the given conditions the tower yard-

Table 3. Mean experimental data.

Yarding variables	Cycle time, s			Distance, m		
	Mean value ±St. dev.	min	max	Mean value ±St. dev.	min	max
Carriage Outhaul (CO)	63.01 ±16.32	20	83	162.6 ±51.3	80	265
Lateral outhaul and hook (LOH)	68.4 ±47.2	27	200	14.4 ±5.6	5	28
Lateral Inhaul (LI)	211.3 ±73.3	75	460	14.4 ±5.6	5	28
Carriage Inhaul (CI)	180.35 ±34.46	186	490	162.59 ±51.3	80	265
Unhook (U)	72.1 ±19.4	30	160			
Delay (D)	180.3 ±79.5	50	450			
Total cycle time	964.6 ±139.7	707	1432			
Delay-free cycle time	883.9 ±112.0	683	1143			
Load volume per cycle (turn), m^3	2.2 ±0.23	1.6	3.0			
Productivity, m^3 per PMH*	9.12 ±1.52	6.76	14.46			
Productivity, m^3 per SMH*	8.41 ±1.61	5.78	13.09			
Number of cycles per SMH*	3.73	2.51	5.09			

Note: * PMH – productive machine hour, SMH – scheduled machine hour.

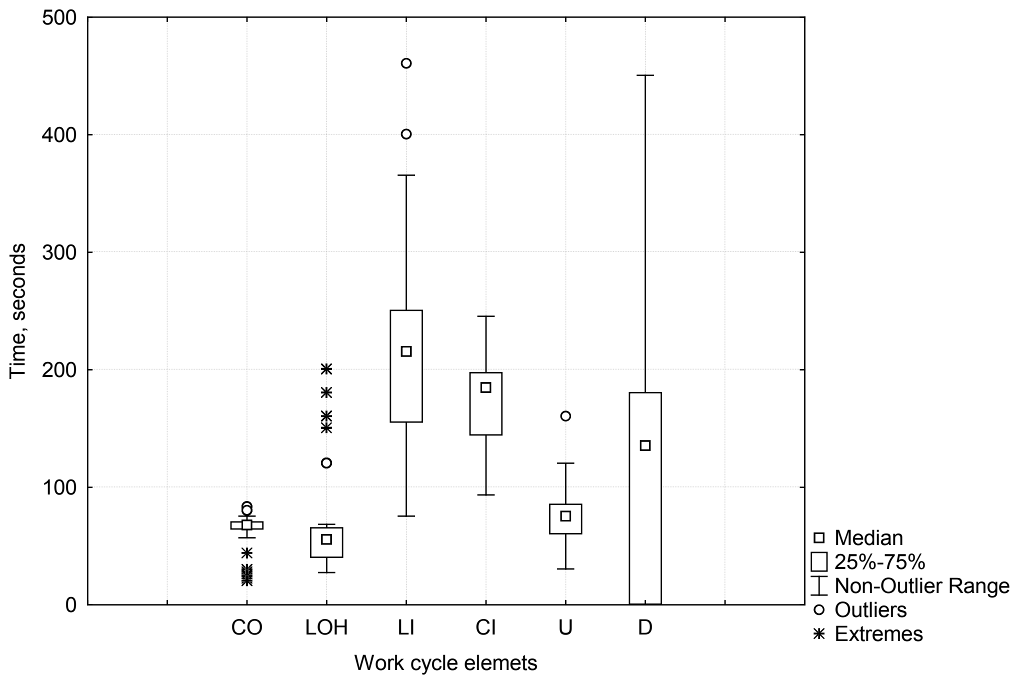

Fig. 1. Elemental time consumption.

er operates at relatively moderate level of yarding distance (mean 162.6 m from nominal length), moderate lateral yarding distance (14.4 m) and slope (20°), and good level of the carriage payload capacity usage.

A regression analysis was performed on the time-study data (using characteristics of independent variables shown in Table 3) in order to develop a prediction equation for estimating the yarding cycle time by excluding and including delays.

The delay-free cycle time T_{net} regression equation obtained with significant variables is shown in Table 4.

Table 4. Summary of the work cycle time models.

Equations		F	R^2	R^2_{adj}	Std. Error	p-value
$T_{net} = 8.88 \cdot l + 14.14 \cdot i$,	(1)	67.44	0.49	0.46	16.13	< 0.05
$T = 0.49 \cdot L + 3.92 \cdot i$,	(2)	4.09	0.20	0.15	112.48	< 0.05

In equation (1) minimum values of delay-free cycle time T_{net} may attain in case of lower rates of lateral yarding distance l and terrain slope angle i. The influence of lateral yarding distance l and terrain slope angle i on delay-free cycle time T_{net} is moderate.

In the equation (2) for cycle time including delays T under the given forest conditions the influence of slope yarding distance L and terrain slope angle i on cycle time including delays T is also moderate (Table 4). Consequently, the minimum duration of total cycle time (including delays) was achieved when slope yarding distance L and terrain slope angle i were minimized.

Productivity of Tower Yarder

To increase delay-free yarding productivity, defined by the equation (3) shown in Table 5, lateral yarding distance l, and terrain slope i should be at low rates, whereas the load volume per cycle V will be at maximum. The influence of mentioned variable on the delay-free yarding productivity is moderate.

From equations (4) shown in Table 5 it can be seen that, when reducing the terrain slope i and increasing the volume of a load to the allowed maximum, it could be expected that the yarding productivity per scheduled machine hour will increase its maximum.

Generally, the mean yarding productivity per hour at mean slope yarding distance of 162.6 m and mean lateral yarding distance of 14.4 m, excluding and including delays, estimates at 9.12 $m^3 \cdot h^{-1}$ and 8.41 $m^3 \cdot h^{-1}$ at the given operating conditions. The mean yarding productivity per hour is higher than the maximum for tower cable yarders, compared to the rates

Table 5. Summary of the productivity models.

Equations		F	R^2	R^2_{adj}	Std. Error	p-value
$P_{PMH} = 6.069 \cdot V - 0.079 \cdot l - 0.24 \cdot i$, $m^3 \cdot h^{-1}$	(3)	13.81	0.45	0.42	1.83	< 0.05
$P_{SMH} = 6.29 \cdot V - 0.20 \cdot i$, $m^3 \cdot h^{-1}$	(4)	7.41	0.31	0.27	2.49	< 0.05

for hardwood quoted by Senturk et al. (2007), Zimbalatti and Proto (2009), Dimitrov (2012), Melemez et al. (2014), and Schweier et. al. (2020).

On the other hand, in order to improve the yarder productivity, a remote control of the carriage is advisable to be used, also by the choker-setter. This way the loaded carriage could wait for the operator before the landing. Another option to reduce choker-setter‘s fatigue and to decrease the time for lateral outhaul and hook is the use of carriage with mechanical slack-pulling.

Cost analysis

The hourly fixed operating and labour cost of the studied tower yarder's three operators, are shown in Table 6 and Figure 2. The gross costs of Koller K501 for uphill whole tree yarding in predominantly beech stand were calculated at 146.52 € per productive machine hour (PMH). Thus, when the studied tower yarder was productive, the extraction costs were at 13.02 €·m^{-3}. The increase of productive time of a tower yarder would lead to a decrease in extraction costs.

Table 6. Costs characteristics of the studied tower yarder.

Costs	Costs per PMH, €	Costs, €·m^{-3}	Share of gross costs, %
Fixed costs	18.73	1.65	12.70
Variable costs	55.79	5.00	38.41
Labor costs	48.75	4.30	33.06
Net costs(excluding profit)	123.28	10.96	84.17
Overheads and management costs	7.54	0.67	5.11
Gross costs (including profit)	146.52	13.02	100

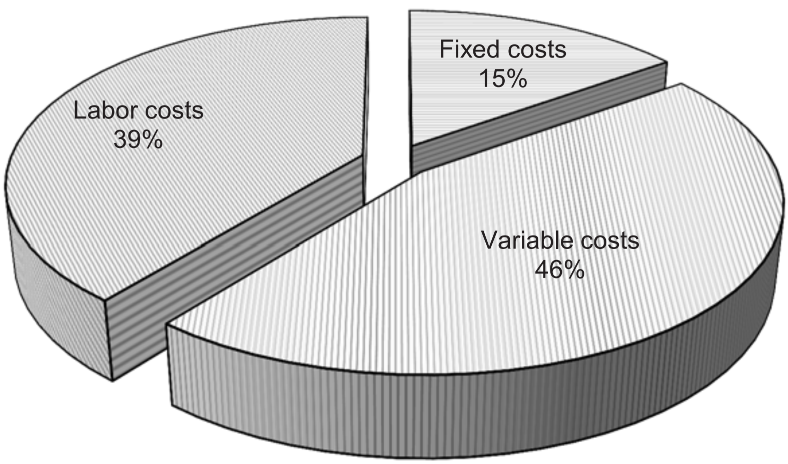

Fig. 2. Percentage distribution of the net yarding costs.

The costs of studied tower yarder are lower compared to the costs of 32.5 ±5.9 €·m^{-3} for Koller K507 and 36.2 ±7.5 €·m^{-3} for Valentini V400 (both including processing at roadside) reported by Schweier et al. (2020).

In the distribution of the net costs (Fig. 2) of the studied Koller K501 tower yarder at these conditions, variable costs predominate; they are more than three times higher than the fixed costs. Generally, the variable costs are almost half of the net cost.

Conclusions

The greatest portion of the cycle time was dedicated to the carriage inhaul (37 % and 29 % respectively, excluding and including delays) and it was most probably related to the low inhaul velocity of carriage with a load. Unhook accounted for the smallest share (10 % and 8 % respectively, excluding and including delays). Lateral inhaul accounted for the second highest share (29 % and 23 % respectively, excluding and including delays), followed by lateral outhaul and hook (13 % and 10 % respectively, excluding and including delays), and carriage outhaul (11 % and 9 % respectively, excluding and including delays). Operational and mechanical delays accounted respectively for 16 % and 5 % of the total cycle time of the studied cable yarder, whereas the productive time for the studied cable yarder was about 78 % of the scheduled machine hour. Operations related to the lateral yarding (the lateral pull of the main line, the chokers hooking, and the extraction of the load to carriage) occupy 42 % within work cycle time including delays, and 53 % within delay-free work cycle.

The mean productivity of a truck-mounted tower cable yarder is close to the maximum for that type (9.12 m^3·h^{-1} and 8.41 m^3·h^{-1}, respectively, excluding and including delays). In order to improve the yarder productivity a remote control of the carriage is advisable to be used, also by the choker-setter. This way the loaded carriage could wait for the operator before the landing. Another option to reduce choker-setter‘s fatigue and to decrease the time for lateral outhaul and hook is the use of carriage with a mechanical slack-pulling.

The gross costs for uphill whole deciduous tree yarding by studied tower yarder were calculated at 146.52 € per productive machine hour and 13.02 €·m^{-3}. In the distribution of the gross costs, labor costs (21.44 %) are lower than variable costs (29.86 %) and fixed costs (26.84 %).

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References

Ackerman P., Belbo H., Eliasson L., de Jong A., Lazdins A., Lyons J. 2014. The COST model for calculation of forest operations costs. International Journal of Forest Engineering 25(1): 75–81.

EFA 2021. Annual report of Executive Forest Agency 2021. Executive Forest Agency (EFA), Ministry of Agriculture, Food and Forestry, Sofia. 75 p.

Boyadzhiev D., Glushkov S. 2021. Investigation of the logging with mountain harvesters in hurricane damaged forest. Forest science 1: 85–102.

Boyadzhiev D., Glushkov S., Chakarov V. 2020. Theoretical basis for determining the optimal distance between corridors of sky line.

Forest science 2: 169–186.

Dimitrov D. 2012. Investigation on work time and productivity of forest skyline Koller K 300 in Ograzhden Mountain. Forestry ideas 18(1): 92–96.

Huyler N.K., LeDoux C.B. 1997a. Cycle-time equation for the Koller K300 cable yarder operating on steep slopes in the Northeast. Research Paper NE-705. Radnor, PA: U.S. Department of Agriculture, Forest Service. Northeastern Forest Experiment Station. 4 p.

Huyler N.K., LeDoux C.B. 1997b. Yarding cost for the Koller K300 cable yarder: results from field trials and simulations. Northern Journal of Applied Forestry 14(1): 5–9.

Kellogg L.D. 1981. Machines and techniques for skyline yarding of smallwood. Research Bulletin 36. Forest Research Laboratory, School of Forestry, Oregon State University, Corvallis, Oregon 97331-7401. 17 p.

Kellogg L.D., Milota G.V., Miller Jr.M. 1996. A Comparison of Skyline Harvesting Costs for Alternative Commercial Thinning Prescriptions. Journal of Forest Engineering 7(3): 7–23. https://doi.org/10.1080/08435243.1996.10702687

Kellogg L.D., Olsen E.D. 1984. Increasing the productivity of a small yarder: crew size, skidder swinging, hot thinning. Research Bulletin 46, Forest Research Laboratory, School of Forestry, Oregon State University, Corvallis, Oregon 97331-7401. 45 p.

LeDoux C.B. 1985a. Stump-to-mill timber production cost equations for cable logging eastern hardwoods. USDA Forest Service. Research Paper NE-566. Broomall, PA, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

LeDoux C.B. 1985b. When is Hardwood Cable Logging Economical? Journal of Forestry 83(5): 295–298.

LeDoux C.B., Huyler N.K. 2000. Cost comparisons for three harvesting systems operating in northern hardwood stands. Research Paper NE-715. Newtown Square, PA, U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 4 p.

Melemez K., Tunay M., Emir T. 2014. A comparison of productivity in five small-scale harvesting systems. Small-scale forestry 13(1): 35–45.

Munteanu C., Ignea Gh., Akay A.E., Borz S.A. 2017. Yarding Pre-Bunched Stems in Thinning Operations: Estimates on Time Consumption. Bulletin of the Transilvania University of Brasov 10(59), Special issue No. 1, Series II – Forestry, wood industry, agricultural and food engineering: 43–52.

Olsen E.D., Hossain M.M., Miller M.E. 1998. Statistical comparison of methods used in harvesting work studies. Corvallis O.R., College of Forestry, Forest Research Laboratory, Oregon State University. 45 p.

Peters P.A., LeDoux C.B. 1984. Stream protection with small cable yarding systems. Northeastern Forest Experiment Station, USDA Forest Service, Morgantown, WV 26505. 17 p.

Proto A.R., Macrì G., Visser R., Russo D., Zimbalatti G. 2018. Comparison of Timber Extraction Productivity between Winch and Grapple Skidding: A Case Study in Southern Italian Forests. Forests 9(2): 3–12.

Proto A.R., Skoupy A., Macrì G., Zimbalatti G. 2016. Time consumption and productivity of a medium size mobile tower yarder in downhill and uphill configurations: a case study in Czech Republic. Journal of Agricultural Engineering 47(4): 216–221. https://doi.org/10.4081/jae.2016.551

Proto A.R., Zimbalatti G. 2016. Firewood cable extraction in the southern Mediterranean area of Italy. Forest Science and Technology 12(16–23). DOI: 10.1080/21580103.2015.1018961

Schweier J., Klein M.-L., Kirsten H., Jaeger D., Brieger F., Sauter U.H. 2020. Productivity and cost analysis of tower yarder systems using the Koller 507 and the Valentini 400 in southwest Germany. International Journal of Forest Engineering 31(3): 172–183. DOI: 10.1080/14942119.2020.1761746

Senturk N., Özturk T., Demir M. 2007. Productivity and costs in the course of timber transportation with the Koller K300 cable system in Turkey. Building and environment 42(5): 2107–2113.

Spinelli R., Lombardini C., Magagnotti N. 2014. The effect of mechanization level and harvesting system on the thinning cost of Mediterranean softwood plantations. Silva Fennica 48(1), 1003. 15 p.

Spinelli R., Magagnotti N. 2011. The effects of introducing modern technology on the financial, labour and energy performance of forest operations in the Italian Alps. Forest Policy and Economics 1(7): 520–524. DOI:10.1016/j.forpol.2011.06.009

Spinelli R., Magagnotti N., Lombardini C. 2010. Performance, capability and costs of small-scale cable yarding technology. Small-Scale Forestry 9(1): 123–135. DOI: 10.1007/s11842-009-9106-2

Spinelli R, Magagnotti N., Cosola G., Labelle E., Visser R., Erber G. 2021. The Effect of Yarding Technique on Yarding Productivity and Cost: Conventional Single-Hitch Suspension vs. Horizontal Double-Hitch Suspension. Croatian Journal of Forest Engineering 43(1): 1–12.

Spinelli R., Maganotti N., Visser R. 2015. Productivity Models for Cable Yarding in Alpine Forests. European Journal of Forest Engineering 1(10): 9–14.

Stoilov S. 2019. Tower yarder work time and productivity study in Rhodope Mountains. Proceedings of the Biennial International Symposium 'Forest and Sustainable Development', 8th Edition, 25–27th of October 2018, Brașov, Romania: 55–65.

Stoilov S. 2021. Logging equipment in Bulgaria – current state and future prospective. Forestry Ideas 27(1): 19–28.

Stoilov S., Proto A.R., Angelov G., Papandrea S.F., Borz S.A. 2021. Evaluation of Salvage Logging Productivity and Costs in Sensitive Forests of Bulgaria. Forests 12(3), 309. https://doi.org/10.3390/f12030309

Stokes B.J., Ashmore C., Rawlins C.L., Sirois D.L. 1989. Glossary of terms used in timber harvesting and forest engineering. General Technical Report SO – 73. New Orleans, LA, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 33 p.

Visser R., Baker S., Sloan H. 2001. Cable logging opportunities in the Appalachian Mountains. In: Arzberger U. and Grimoldi M. (Eds), Workshop proceedings new trends in wood harvesting with cable systems for sustainable forest management in the mountains, Ossiach, Austria, 18–24 June 2001, Joint FAO/ECE/ILO Committee on Forest Technology, Management and Training with the participation of the IUFRO, Rome, 2003. Available at: http://www.fao.org/3/Y9351E/Y9351E17.htm#ch17

Zimbalatti G., Proto A.R. 2009. Cable logging opportunities for firewood in Calabrian forests. Biosystems engineering 102(1): 63–68.