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An Investigation in Roundwood Extraction of *Fagus sylvatica* and *Calabrian Pine* by Greifenberg TG700

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Abstract

Cable yarding is especially popular in the European mountains, where slope and roughness parameters are limits for ground-based harvesting technology. This system, most commonly steep slope harvesting techniques worldwide, is poorly diffused in Southern Italy. The study was conducted in two forests in the Apennine mountain range. The time and motion study was conducted using the repetition timing method to determine the total yarding cycle time. We measured the impact of the following independent variables on the “total cycle time” (total time) and on the “productivity”. The productivity study carried out showed that the work capacity of cable crane tested was satisfactory. Using the Greifenberg TG700, the extraction costs were calculated as 17.70 € per m^3 at site A and 17.44 € at site B, where these costs refer to the working time (productive + unproductive time).

Keywords: Productivity, Extraction, Cost, Time consumption, Cable crane

1. Introduction

In the last ten years, several types of cable crane are marketed with different characteristics in terms of size, power, extraction system, gravity system, and loading capacity. All-terrain mobile tower cable cranes are promising innovations, which can operate under conditions with different soils. New forms of equipment are released periodically to respond to the increasing needs of producers regarding productivity, operator safety, and product quality. Cable cranes with universal carriages, in fact, are not limited to a narrow working area and they can be very efficient in locations where other forms of wood extraction are not possible or permissible due to various natural or ecological limitations. The aim of this study was to investigate the productivity of mobile cable crane, Greifenberg TG700, in two different sites characteristic of Southern Italy. The time and motion study was conducted using the repetition timing method to determine the total yarding cycle time.

2. Materials and Methods

Greifenberg TG 700 cable crane was monitored and all the data was collected in the two test sites. Similar to other studies conducted to determine the performance and cost of cable yarding technology, we analyzed time consumption data using the general concepts employed in observational modeling studies [8, 9, 13, 17]. The study was conducted in two forests in the Apennine mountain range, in Southern Italy. The forests considered are a beech (*Fagus sylvatica*) in site A (stand Pollino) and pine (*Calabrian Pine*) in site B (stand Sila), high forest, at an altitude of 1,450 m a.l.s for site A, and 1,250 in site B (Fig.1). The study was conducted in selective felling site, on area of 14 ha with N-E exposition in A, and 20 ha with N-O exposition in B. The forests land are classified as I class for roughness, while the slope is between II class and III (20/60%). The stand density was 850 trees for hectare in site A and 900 for site B. The total volume was 630 m^3/ha in site A and 720 m^3 in B. The timbers extracted was trees with an average height of 19 meters and an average diameter of 30 cm in site A and an average diameter of 32 cm in site B with height of 24 meters. The volume of average tree was 0.80 m^3 in site A and 0.70 in site B (table 1).The density of the forests is generally uniform in both sites; small gaps are present only in the areas with lower soil depth. The areas not have a main road network; the trails opened during felling were used as the secondary road network. In both sites the work system adopted was the Full Tree System (F.T.S.). The logs were then transported to the landing where they were bucked and loaded into a truck. The volume of each tree was calculated using Smalian's formula by multiplying the average cross-sectional area of the stem by the stem length [10]. Selective cut was adopted and was removed 25% per hectare in both sites. A team of four workmen operated in the timber yards in sites A and B. The working group consisted one haulage engineman, two workers for yarder and one worker for timber unloading in landing site. Selective cut was adopted and was removed 25% per hectare in both sites. The operating area of the cable crane was about 2.40 ha at site A and 2.80 ha at site B.

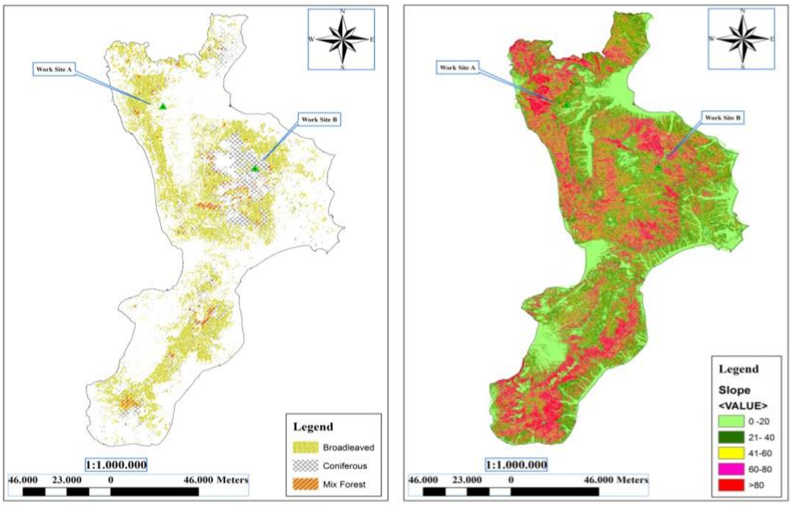

Fig. 1. Geographic location the research areas and maps of the slope

Table 1. Test sites characteristics

Work Site	**A**	**B**
Placename	Mormanno	San Giovanni in Fiore
Province	Cosenza	Cosenza
Elevation m (asl)	1,450	1,250
Species	Beech	Calabrian Pine
Stand Type	Hig forest	Higt forest
Operation	Selective cut	Selective cut
Density (tress /ha)	850	900
Volume site (m³/ha)	630	720
Removal trees (ha)	213	225
Removal m³/ha	157	180
Average tree m³	0.8	0.7
Average DBH (cm)	30	32
Average Slope gradient (%)	51	33
Extraction (direction)	Uphill	Uphill

2.1 Tower Yarder

The investigated mobile cable crane is a Greifenberg TG700 which is a mobile cable crane designed for extracting wood uphill. The system comprises two principal lines: skyline and mainline. The basic characteristics of the cable crane are as follows:

- cable crane mass is 6000 kg (with winch, ropes and engine);
- diesel engine power is 84 kW;
- 4 Guylines of 40 meter length and 12 mm of diameter;
- skyline drum capacity of 700 meters;
- carriage type Crg 25 is automatic.

2.3 Time consumption and productivity study

Similar to other studies conducted to determine the performance and cost of cable yarding technology, we analyzed time consumption data using the general concepts employed in observational modeling studies [3, 5, 12, 13, 15, 17]. The time and motion study was conducted using the repetition timing method to determine the total yarding cycle time, i.e., the amount of time required for the carriage to travel from the landing until the unhooking of the payload. These activities were investigated in terms of the cycle times by using stopwatches for each individual cycle, where we separated the productive time from the delay time, as well as identifying the variables that were most likely to affect the time consumption [2]. Seven yarding elements were identified and timed to determine the total cycle time [6]:

Outhaul Empty: Begins when the operator is ready to move the carriage from the landing out to choke setter and ends when the choke setter touches the choke.

***Hook descent*:** Begins when the operator locks the carriage and begins to release the hook, and it ends when the operator starts to connect with the load.

Lateral Out: Begins at the end of outhaul empty and ends when the choke setter is ready to hook a turn. (Choke setter's forward motion has stopped and is ready to begin setting the chokers).

Hookup: Begins at the end of lateral out and ends when the choke setter has completed hooking the chokers and signals to begin yarding.

Lateral in: Begins at the end of hookup and ends when the turn is pulled up to the carriage and the carriage begins to move up the corridor.

In haul: Begins at the end of lateral in and ends when the turn has reached the position on the deck where it can be directly unhooked at the landing.

Unhook: Begins at the end of in haul when the carriage passes over the trip block and ends when the chokers have returned to the carriage.

In practice, 140 cycle times were recorded in total to determine the average performance at each site (A and B). The time data were recorded by two researchers, i.e., one stationed with the timber at the bunching location and the other stationed next to the cable system. Wireless communication was maintained between these researchers. During the trials, the Greifenberg TG 700 was operated by the remote control, both from the landing and the stand (when setting the chokers). The in and out haul functions of the drums were synchronized by computer, so the operators only used simple orders to control the yarder [8]. The machine costs were calculated as described by Miyata (1980) [11] for forest machine and by using the COST model proposed by Ackerman *et al.* (2014) [1]. In order to calculate the production cost for 1 m^3 of wood, 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 wood extracted, and productive machine hours excluding all delay times.

Data analysis

We measured the impact of the following independent variables on the "total cycle time" (total time) and on the "productivity". We used the total cycle time as a dependent variable whereas "Lateral distance, Skyline slope distance, volume and Slope" were selected as independent variables. For the model productivity "*Lateral Distances, Skyline slope distances and number trees for turn*" were selected as independent variables. The definitions of independent variables as well as their measurements are summarized as follows:
Lateral distance: The lateral yarding distance in feet was measured either by pacing the distance or by ocular estimation of the distance to the nearest 10 m.
Skyline Slope Distance: On each corridor, the ground slope distance in feet was measured and marked at regular intervals to aid in recording slope distance that the carriage traveled during the study period.
Volume**:** Each piece was measured in the corridor and marked with an identification number and recorder by turn number. The large – and small – and diameters and length were scaled.
Slope: was classified in terms of gradient and topographic form of the slope with GPS and maps of slope of the region Calabria.
Number of trees for turn: The number of stems per cycle were recorded.
All of previous independent variables are considered to be scale variable (Eq. 1). Theoretically, the following mathematical equation is obtained.
Total cycle time = f (*Lateral distance, Skyline slope distance, Volume and Slope*) Eq. 1
SPSS and Excel 2012 were used for the analysis. A regression model was developed for the statistical analysis. Initially, a 95% significance level was set to test the null and alternative hypotheses given above.

3. Results and discussion

The table 2 shows the average time of the cycle in two sites. Generally the time of a cycle of timber haulage in site A was 8.55 minutes, while in site B was 11.26 minutes.

Table 2. Time consumption (min+SD) per working component

Phases	Site A				Site B			
	Min	**Mean**	**Max**	**Dev St**	**Min**	**Mean**	**Max**	**Dev St**
Outhaul Empty	1.01	2.41	4.21	0.91	1.5	2.7	5.25	0.87
Hook descent	0.11	0.19	0.31	0.04	0.15	0.39	1.1	0.23
Lateral Out + Hook Up + Lateral In	1.23	2.31	4.5	0.78	2.25	3.51	5.15	0.6
In Haul	2.01	3.25	5.59	0.95	2.2	3.59	6.25	0.8
Unhook	0.1	0.18	0.9	0.13	0.2	0.51	1.28	0.25
Delay time	0.1	0.2	0.9	0.16	0.25	0.53	1.2	0.25
Cycle time	5.62	8.55	12	1.63	7.7	11.2	17.28	1.94

The average timber haulage times were 8.55 min at site A and 11.26 min at site B. Regression analysis was performed on the Grefeinberg TG 700 time study data to develop a delay free cycle time equation for the machine under the stand conditions stated in the study. The variables included for both sites skyline slope distance, lateral distance, slope and volume per turn cubic. The cycle – time equation for the site A took the form:
Cycle Time (minutes) = 3.075 + 0.049 * Lateral distance + 0.005 * Skyline slope distance + 0.067 * Volume + 0.051 * Slope **R^2**= 0.71
In site B the cycle – time equation took the form:
Cycle Time (minutes) = 2.516 + 0.047 * Lateral distance + 0.013 * Skyline slope distance + 0.401 * Volume + 0.125 * Slope **R^2**= 0.73
Lateral distance, Skyline slope distance and slope ($p < 0.0005$) showed a significant contribute, Volume ($p > 0.05$) shower a reduced and a non-significant contribute in both sites.
The total volumes were 2,198 m^3 at site A and 3,600 m^3 at B, i.e., 157 m^3 ha^{-1} for site A and 180 m^3 ha^{-1} for site B. On average, a worker produced 7.24 m^3 d^{-1} at site A and 7.35 m^3 d^{-1} at site B. The low difference between the two sites (A and B) was directly dependent on the extraction distance, slope and the volume of each load. In particular, the length of the logs influenced the time required for extraction and bunching at both sites. In fact, the number of logs in each load (two or three in the most of the cases) and the speed of the transport were restrained in order to reduce residual stand damage. The average delay time was 0.28 min/cycle in site A, and 0.52 in site B. The lost time occurred during the loading and unloading of the carriage. The mounting and dismounting of this cable crane was easy, fast and the productivity was low influenced (Table 3). Thus, the yarding of semi-suspended trees is only compatible with uphill extraction. Given the lengths of the trees extracted, it might be helpful to employ a carriage that extracts long loads in a fully horizontal direction or to increase the distance of the skyline cable above the ground. Two independent operating hoisting winches mounted on the carriage could allow the horizontal transport of long and high loads even with a small distance between the skyline cable and ground. This could increase the speed of extraction and thus the productivity of the yard.

Table 3. The average daily operative results of the work site

	Unit	Greifenberg TG 700	
		Site A	Site B
Wood Harvest Systems		Full Tree System	
Number of valid observations	n.	70	70
Yard cycles			
• Average volume per cycle	m^3	1.38	1.59
• Yarding cycle per day	n.	42	37
• Yarding cycle per hour	n.	6-7	5-6
• Average time for one cycle	min.	8.55	11.26
• Standard deviation (σ)	±	1.63	1.94
Productivity			
• Daily SMH	$m^3\ d^{-1}$	57.96	58.83
• Daily PMH	$m^3\ d^{-1}$	77.28	67.68
• Hourly SMH	$m^3\ h^{-1}$	7.24	7.35
• Hourly PMH	$m^3\ h^{-1}$	9.66	8.46
Manpower			
• Operators	n.	4	4
• Work capacity	$m^3\ h^{-1}$-man	1.81	1.83
• Unit Time	$h\ m^{-3}$	0.14	0.12
• Productivity	h-man m^{-3}	0.55	0.54

The fixed and hourly operating costs for the cable crane are shown in Table 4. Using the Greifenberg TG700, the extraction costs were calculated as 17.70 € per m^3 at site A and 17.44 € at site B, where these costs refer to the working time (productive + unproductive time).

Table 4. Calculation of hourly costs of cable crane

Parameter	**Value**	**Parameter**	**Value**
Purchase price (€)	150,000	Interest cost (€)	6,720
Salvage value (€)	30,000	Taxes and insurance (€)	3,840
Economic Life (y)	10	Total fixed cost (€ h^{-1})	20.14
Yearly utilization (n)	140	Total variable cost (€ h^{-1})	48.05
Scheduled operating time (h)	1120	Total labour cost (€ h^{-1})	20.00
Annual depreciation (€)	12,000	Total cost (€ h^{-1})	68.20

Thus, when the cable crane was productive, the extraction costs were 13.27 € per m^3 at site A and € 14.20 at site B. The delay times increased the operating cost by 4.43 € (25%) at site A and 3.24 € (19%) at site B. Therefore, it is necessary to reduce the unproductive time in order to increase the site productivity, thereby reducing the extraction costs. In order to lower the fixed and operating costs of the cable cranes, it is necessary to increase the number of annual working days. The test of the cable crane obtained satisfactory results but a number of organizational features could be improved in order to fully exploit its potential. The cost per cubic meter and efficiency are influenced greatly by the productivity.

4. Conclusions

The objective of this study was to analyze the productivity of Greifenberg TG 700 sites in two different using a time motion methodology. No significant differences in productivity and costs were found between site A and site B. In this study, productivity (SMH) was found as 7.24 m^3h^{-1} for transporting distance (for average 155 m) in site A, and 7.35 m^3h^{-1} (for average distance 176 m) in B, causes number of tress per turn. The acquired data and the resulting analysis focused on the bunching operation since it is one of the most critical working elements of logging. Even though the productivity of the tested crane was lower than other cable cranes used outside Italy, the data obtained throughout this study was higher than 0.5 m^3 m^{-1}, the necessary minimum for economic logging with traditional cableway and 0.2 m^3 m^{-1}, the necessary minimum for economic logging with cable cranes in Italy. Unproductive time should be reduced by employing workers specialized in cable system operations; and maintenance and repair of carriages, chokers, and cables must be done at the start of the activity. Finally, the high purchase price of this type of machine may be discounted against its minimal negative impact on the environment and the fact that it may be the only viable and sustainable extraction method for the management of sensitive sites [6, 14, 16]. Interaction between silviculture and logging operations remain particularly important on steep terrain. For cable systems, communication between the forest manager (who marks the trees to be removed) and the logging company (who calculates the location of the lines) is essential [8, 9]. Further research into cable extraction systems could employ a global navigation satellite system installed in the carriage to support automatic or semi-automatic operational monitoring, as well as improving the quantity of data acquired to reduce the workload of the surveyor [4, 5].

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