

Time consumption and productivity of a medium size mobile tower yarder in downhill and uphill configurations: a case study in Czech Republic

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Abstract

Cable cranes are among the most important means of yarding and transporting timber in many mountainous regions of Europe. In the last decade, all-terrain mobile tower cable cranes have been increasing due to their adaptability to operate both in uphill as well in downhill configuration. This research assesses the efficiency and the costs of a mobile cable crane manufactured in Czech Republic and designed for all-terrain application and specifically mounted on a wheeled agricultural tractor. A total of 100 cycle times were recorded in order to obtain evaluate the performance in the downhill as well uphill extraction configuration. The productivity analysis was based on regression equation as a function lateral distance, skyline slope distance and extracted volume. Increasing in number of lateral distance and extraction distance resulted as significant variables affecting the cycle time. Even if the test highlights a good efficiency of the extraction system for both the configuration (uphill *vs* downhill) there a still many organisational features that could be improved in order to fully exploit the potentiality of the tested cable crane system.

Introduction

Cable yarding has been used extensively in Central Europe since the 1970s when mobile integrated tower yarders were introduced (Heinimann *et al.*, 2001). Nowadays it is well recognised that cable

yarding represents a low impact system for extracting wood in steep terrain both on soil as well on residual stand trees (Stampfer *et al.*, 2006). Again, on steep terrain, cable yarding could be a cost-effective alternative to building an extensive network of skidding trails and results in a much lower site impact compared to ground-based logging (Worrell *et al.*, 2011; Stanczykiewicz *et al.*, 2015), as well it seems to be competitive in terms of CO₂ in comparison to semi-mechanised ground-based logging (Cosola *et al.*, 2016).

During the last ten years, new cable crane models have been developed for applications in conditions where the terrain prohibits the use of other techniques. A recent study highlights that the annual utilisation of cable yarding systems in Austria is between 560 and 1500 h productive machine hours (Holzleitner *et al.*, 2011).

All-terrain mobile tower cable cranes are one of the promising innovations; all-terrain system can operate under different terrain characteristic (steepness, soil wet condition, *etc.*) independently from the extraction direction (Heinimann *et al.*, 2001). Cable cranes with universal carriages 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 (Klun *et al.*, 2005). Anyway in the last decades more than 50 works have analysed the efficiency and the impact of cable yarder (Cavalli, 2012) highlighting the strong interest of the scientific community on the topics.

The purpose of this study is to investigate the productivity of mobile cable cranes mounted on a 4WD agricultural tractor, which has been occasional, investigated till now with the aim to evaluate the significant variables affecting the extraction operation efficiency.

Materials and methods

Cable yarder unit

The tested mobile cable crane is the Larix Lamako, which is a mobile cable crane, designed for extracting wood downhill as well as uphill. The system can be classified as a four rope-system as it comprises a skyline, a mainline, a haul-back line and an assembly line (Table 1). The cable crane is designed with a super structure, which is mounted on the rear three-point linkage (tower with winches) and on the front three-point linkage (storage drums, assembly drum, and carriage) of an agricultural 4WD tractor. The total mass (11,200 kg) (tractor and cable crane) is distributed for 70% on rear axle of tractor and the complete unit is also very mobile on difficult terrain (Kováčik and Stoilov, 2009; Klva *et al.*, 2012). The acronym of this system *Lamako* means *lanovka pro malékoncentrace* (standing skyline yarding system for small wood densities) and it was introduced in 2008 (Kováčik and Stoilov, 2009). The carriage is a MM-Sherpa U3t in a 3-cable system configuration (Mayr-Melnhof Forsttechnik GmbH, 2009) (Figures 1 and 2). The clamps of the carriage are controlled by a remote system

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device, which gives the advantage, that the carriage can be stop and blocked at any position along the skyline. The mainline is mechanically slack pulled to the logs by using the power of the haul-back line winch while the skyline clamp is active. The MM-Sherpa U3t carriage has a suitable haul-back line drum capacity for the lateral yarding distance. The logs are yarded laterally to the carriage using the power of the yarder's mainline winch and active skyline clamps (Proto and Zimbalatti, 2015).

Study site and work organisation

The case study was situated in the Krtiny Training Forest Enterprise in the municipality of Brno at an altitude of about 400 m a.s.l. (Hurt *et al.*, 2014) (Figure 3). The area covered about 6 ha with a N-O exposition. The Larix Lamako was used in two spruce (*Picea abies* L.) stands (sites A and B, Table 2) where site A was located downhill from the main access road (wood is here yarded uphill to the road), whereas site B was uphill of the main trail (wood is here yarded downhill to the road). Selective cut was adopted and was removed 20% of volume per hectare in both sites. The operating area of the cable crane was about 1.46 ha at site A and 1.05 ha at site B, where the differences in height between the two extremities of the line were 32 m at site A and 23 m at site B. The two stands were quite similar and the operators worked in the same manner during both tests and in both areas (A and B). A single span line was mounted and two supports were used to hold the haul-back line off the ground in both sites. The tower was stabilised with four guy lines fixed around anchor trees.

The tree-length system, which consists in felling, delimiting and top-

ping trees at the stump area was used in both the cases (Table 2). 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 (Philip, 1994). The lengths of timber ranged from 14 to 17 m. At sites A and B, teams of 4 operators were working in the timber-yard: a yarder operator, two choker setters, and an operator for timber unloading.

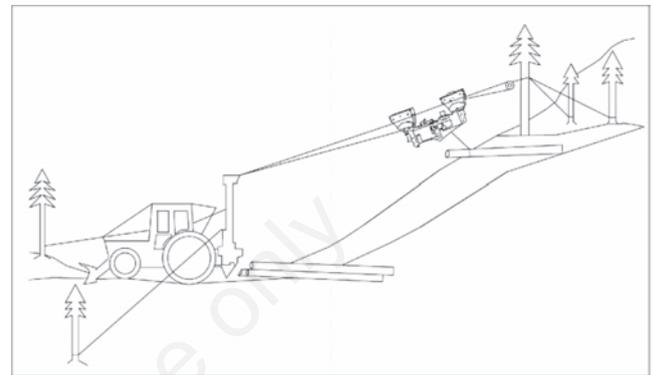


Figure 1. Setting of the cable crane while working at site A.

Table 1. Technical characteristics of the cable crane.

Characteristics	Larix Lamako
Tower	
- Type	Hinged
- Height (m)	8
Guylines	
- Number	6
- Diameter (mm)	10
- Length (m)	200
- Pulling force (kN)	6
Winch	
- Main line drum capacity (m)	550
- Diameter of mainline (mm)	10
- Main line pulling force (kN)	27
- Skyline drum capacity (m)	550
- Diameter of skyline (mm)	16
- Skyline cable tensioning force (kN)	45
- Haul-back line drum capacity (m)	
- Diameter of mainline (mm)	1100
- Main line pulling force (kN)	10
	20
Engine power (kW)	70+
Weight total (kg)	4100
- Loading rear axle of tractor (kg)	3000
- Loading front axle of tractor (kg)	1100
Carriage	
- Type	Automatic
- Model	MM- Sherpa U3t
- Size (width × depth × height - cm)	203 × 46 × 105
- Weight (kg)	453
- Safety brake	Present
- Loading capacity (kN)	30



Figure 2. MM-Sherpa U3t Carriage.

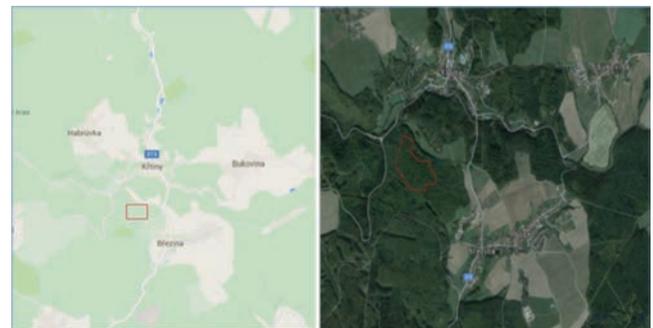


Figure 3. Krtiny Training Forest Enterprise in Brno province and the felling area.

Time consumption and productivity study

Similar to other studies to determine the performance and cost of cable yarding technology, this study analysed time consumption data using the general concepts employed in observational modelling studies (Aykut, 1986; Zimbalatti and Proto, 2009; Spinelli *et al.*, 2010; Borz *et al.*, 2014). 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 (Balimunsi *et al.*, 2012). Six yarding elements were identified and timed to determine the total cycle time (Huyler and Ledoux, 1997):

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.

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).

Hook up: 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 hook up 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 and ends when the chokers have returned to the carriage.

In practice, 100 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 Larix Lamako was operated by the remote control, both from the landing and the stand (when setting the chokers). The in haul and the out haul functions of the drums were synchronised by computer, so the operators only used simple orders to control the yarder (Kováčik and Stoilov, 2009).

The machine costs were calculated as described by Miyata (1980) for forest machine and by using the COST model proposed by Ackerman *et al.* (2014). In order to calculate the production cost for 1 m³ 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. The machine costs per hour were reported both as productive machine hours excluding delays and scheduled machine hours. The purchase prices and operator wages required by the cost calculations were obtained from catalogues and accounting records.

Data analysis

We measured the impact of the following independent variables on the *total cycle time* (total time). We used the total cycle time as a dependent variable whereas *lateral distance*, *skyline slope distance* and *volume* were selected as independent variables.

The definitions of independent variables as well as their measurements are summarised as follows:

Lateral distance: the lateral yarding distance 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 was measured by tape meter and marked at regular intervals to aid in recording slope distance that the carriage travelled during the study period.

Volume: each log in the corridor was measured by caliper and tape meter and marked with an identification number and recorder by turn number. The volume was determined according to the Huber's Formula.

All of previous independent variables were considered and included the following theoretical equation:

$$\text{Total cycle time} = f(\text{Dir_Dummy, Lateral distance, Skyline slope distance, Volume}) \quad (1)$$

where Dir_Dummy = 1 for Uphill and 0 for downhill.

A spreadsheet was compiled with the collected data and used then in the SPSS software for the statistical analysis. A regression model was thus developed. Initially, a 95% significance level was set to test the null and alternative hypotheses given above. An F-test (variance analysis) was used thus to test whether the data satisfied the statistical model, *i.e.*, F-test = 7.88 which were statistically significant at P < 0.005.

Results and discussion

The average timber haulage times for the Larix Lamako were 8.45 min at site A and 9.11 min at site B (Table 3). Regression analysis was performed on the Larix Lamako 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 skyline slope distance, lateral distance and volume per turn.

The volume of an average piece of timber was 0.30 m³ and its length was 15 m at site A. At site B, the volume of an average piece of timber was 0.24 m³ and it measured 14 m. The total volumes were 163 m³ at site A and 111 m³ at B, *i.e.*, 112 m³ ha⁻¹ for site A and 106 m³ ha⁻¹ for site B. On average, daily productivity per operator was 6.02 m³ day⁻¹ at site A and 4.96 m³ day⁻¹ at site B. The difference between the two sites (A and B) was directly dependent on the extraction distance and the volume of each load. In Figure 4 data from individual cycle observations

Table 2. Characteristics of the test sites.

Area	Work site A	Work site B
	Masaryk Forest Krtiny	
Altitude (m a.s.l.)	550	490
<i>Forest</i>		
- Species	Spruce	Spruce
- Silvicultural system	High forest	Selective cut
- Stand density (trees ha ⁻¹)	725	650
- Total volume (m ³ ha ⁻¹)	558	525
Average slope (%)	48	28
Average lateral pull (m)	43	35
Yarding direction	Uphill	Downhill
Roughness	Average	Highly
Length of line (m)	195	180
Difference in height between the two ends of the line	32	23
Average sag (m)	3.15	2.50

were analysed with regression technique in order to calculate relationship between productivity and distance.

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. The lost time occurred during the loading and unloading of the carriage. Our evaluations of efficiency in organisa-

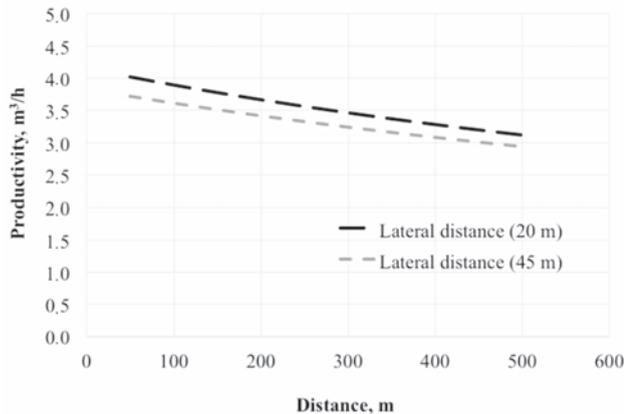


Figure 4. Relationship between productivity and extraction distance.

tional and economical terms showed that for the Larix Lamako machine, the volume harvested per field length of cable line was 0.84 m³ m⁻¹ at site A and 0.65 m³ m⁻¹ at site B. This indicator assessed the relationship between the total volume of yarded trees and the field length of the cable crane line. The mounting and dismounting of this cable crane was easy, fast and the productivity was low influenced (Table 4). An important factor that restricted the bunching and extraction times at both sites was the harvesting method. The maximum lat-

Table 3. Time consumption (min ± standard deviation) per working component.

Phases	Larix Lamako		
		Work site A	Work site B
Outhaul empty	Min (SD)	1.65 (0.16)	1.84 (0.80)
Lateral out + hook up + lateral in	Min (SD)	2.95 (0.44)	2.80 (0.44)
In haul	Min (SD)	3.30 (0.18)	3.35 (0.18)
Unhook	Min (SD)	0.31 (0.05)	0.34 (0.05)
Delay time	Min (SD)	0.24 (0.04)	0.30 (0.04)
Total	Min (SD)	8.45 (0.36)	9.11 (0.69)

SD, standard deviation.

Table 4. Average daily operating results at the work sites.

Wood harvest systems	Unit	Larix Lamako	
		Work site A	Work site B
Tree length system			
Number of valid observations	n.	100	100
Total duration of observations without mounting and dismantling times	h	17.39	19.51
Yard cycles			
- Average volume per cycle	m ³	0.52	0.48
- Yarding cycle per day	n.	46	41
- Yarding cycle per hour	n.	6	5
- Average time for one cycle	Min.	8.45	9.11
- Standard deviation (σ)	±	0.36	0.69
- Coeff. of variation	%	4.28	8.08
Productivity			
- Daily SMH	m ³ d ⁻¹	23.92	19.68
- Daily PMH	m ³ d ⁻¹	29.52	23.84
- Hourly SMH	m ³ h ⁻¹	2.99	2.46
- Hourly PMH	m ³ h ⁻¹	3.69	2.98
Manpower			
- Operators	n.	4	4
- Work capacity	m ³ h ⁻¹ -man	0.75	0.62
- Unit time	h m ⁻³	0.33	0.41
- Productivity	h-man m ⁻³	1.34	1.63
Incidence of mounting and dismantling times in 100 trips observed	h	1.12	1.39
Total duration of observations including incidence of mounting and dismantling times	h	18.51	20.90
Mounting and dismantling times	h	3.50	2.70
Productivity			
- Volume per 100 cycles	m ³	52	48
- Daily	m ³ d ⁻¹	22.48	18.57
- Hourly	m ³ h ⁻¹	2.81	2.32
- Unit time	h m ⁻³	0.36	0.43

eral yard distance, *i.e.*, 45 m at site A and 40 m at site B, did not facilitate the bunching operations for trees when using the tree-length system. The lengths of timber ranged from 14 to 17 m and the travelling load was partially suspended, where it bumped into the lower parts of trees and the soil, which forced the operator to extract at a speed lower than the full potential of the carriage, despite directional felling was performed properly. 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 different carriage respects MM-Sherpa U 3t 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, for example, 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. The present study showed that the cable crane extracted lower average volumes of timber (0.50 m³) compared with the full load potential of the carriage. In particular, the use of a 1.5 t carriage could be more appropriate in this place compared with the 3 t load capacity of the carriage used. The limited average extracted volume recorded in this study may have depended on the work method employed rather than the machine capacity. It is known that the preparation of loads has an important effect on the efficiency of load extraction.

The fixed and hourly operating costs for the cable crane, included labour cost of four operators, are shown in Table 5. Using the Larix Lamako, the extraction costs for wood were calculated as 42.97 € per m³ at site A and 52.22 € at site B, where these costs refer to the working time (productive + unproductive time). Thus, when the cable crane was productive, the extraction costs were 34.79 € per m³ at site A and 43.08 € at site B. The delay times increased the operating cost by 8 € (19%) at site A and 9 € (17%) at site B. The number of valid observa-

Table 5. Calculation of hourly costs of cable crane included four operators.

Parameter	Value	Parameter	Value
Purchase price (€)	175,000	Interest cost (€)	2742
Salvage value (€)	35,000	Taxes and insurance (€)	8773
Economic life (y)	15	Total fixed cost (€ h ⁻¹)	27.72
Yearly utilisation (n)	160	Total variable cost (€ h ⁻¹)	17.75
Scheduled operating time (h)	1280	Total labour cost (€ h ⁻¹)	90.00
Annual depreciation (€)	9333	Total cost (€ h ⁻¹)	128.47

Table 6. Regression model parameters for Larix Lamako.

Model	Sum of squares	df	Mean square	F	Sig.	
1	Regression	1.314	2	0.657	8.198	0.001
	Residual	5.449	68	0.080		
	Total	6.762	70			

Model	Unstandardised coefficients	Standardised coefficients	t	Sig.		
	B	Std. error	β			
1	Constant	7.005	0.386	-	18.168	0.000
	Lateral distance	0.026	0.008	0.346	3.143	0.002
	Skyline slope distance	0.005	0.002	0.228	2.071	0.042

df, degree of freedom; Sig., significance; Std. error, standard error.

tions collected during the tests was large enough to develop reliable model for predicting cycle time. The cycle-time equation for the Larix Lamako took the following form:

$$\text{Cycle Time (min)} = 7.005 + 0.026 * \text{Lateral distance (m)} + 0.005 * \text{Skyline slope distance (m)}$$

$$R^2 = 0.44 \quad (2)$$

The F-test (variance analysis) results were reported in Table 6. It is possible to observe how Lateral distance ($P < 0.001$) and Skyline slope distance ($P < 0.005$) showed a significant contributes, Dir Dummy (1) and Volume ($P > 0.005$) had instead a non-significant contribute.

The productivity model was calculated with the significant variables of the equation of the total cycle time.

The utilisation rates determined by this study are not much different than those reported by Spinelli *et al.* (2010) in Italy for two tower yarder models and in Turkey by Ozturk and Senturk (2006) for uphill and downhill extraction of spruce timber. The test of the cable crane obtained satisfactory results but a number of organisational features could be improved in order to fully exploit its potential.

Conclusions

The objective of this study was to analyse the productivity of Larix Lamako in two different cases (downhill and uphill extraction configurations) using a time motion methodology. No significant differences in productivity were found between downhill and uphill extraction direction as well in terms of extracted volume. On the other hand, lateral distance and skyline slope distance show a significant effect on the productivity. The acquired data and the resulting analysis focused on the bunching operation since it is one of the most critical working elements of logging.

In conclusion, the possibility of applying agricultural tractors with a mobile cable crane system (downhill and uphill) may improve the spread of this method in small enterprises. The development of new tools and methods will allow forest enterprise to operate in woodlands that lack roads and infrastructure, as well as overcoming problems with uneven terrain, which can reduce the income from operations. The reduced investment costs could also allow their use for the production of firewood or in areas where the level of mechanisation is not widespread and still at an early stage.

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