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Productivity of TIMBERJACK 240A and LKT 81T Skidders at Selective Cutting and Longer Distances

Dane Marčeta[1,*], Senaid Handžić[2], Mladen Đukić[3], Vladimir Petković[1]

(1) University of Banja Luka, Faculty of Forestry, Bulevar Vojvode Petra Bojovića 1a, BA-78000 Banja Luka, Bosnia and Herzegovina; **(2)** Public Forestry Enterprise "ŠPD-ZDK" Ltd., Alije Izetbegovića 25, BA-72220 Zavidovići, Bosnia and Herzegovina; **(3)** Public Forestry Enterprise "Šume Republike Srpske", Forest Administration "Vrbanja", Cara Dušana 48, BA-78220 Kotor Varoš, Bosnia and Herzegovina

*** Correspondence:** e-mail: dane.marceta@sf.unibl.org

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ABSTRACT

The extraction of wood from forests is a difficult, risky, expensive, and time-consuming operation, especially in mountainous areas and selective forests. In the forestry of Bosnia and Herzegovina (BIH), winching and skidding of wood assortments is most often done with cable skidders. They are the most applicable because they can handle hilly, mountainous and inaccessible terrain in the compartments that are most common in local forestry. In addition, selective and group-selective forest management systems are dominant, where the manoeuvring of any type of machinery is strictly limited to the skid trails and skid roads. It is a matter of legal and sub-legal regulations and environmental standards. Striving for higher productivity and economy of skidding is ultimately one of the objectives of forest management. Different Timberjack and LKT models of skidders are widely used in BIH. The study was conducted in the area of two public forest enterprises, in compartments 32 (Forest management unit "Vrbanja") and 99 (Forest management unit ""Lješljanica-Maglajska") with similar stand and relief conditions. The research objects were two skidders, which are used very often in the forestry of BIH, LKT 81T and Timberjack 240A. Skidder LKT 81T was used in compartment 32, where 29 cycles were recorded, during which 212 logs were skidded. Total volume of skidded wood was 159.98 m^3 with average volume of 5.52 m^3·load^{-1}. Timberjack 240A was used in compartment 99, where 84 cycles were recorded, with 398 logs. Total skidded wood with Timberjack 240A was 657.34 m^3, with average volume of 7.83 m^3·load^{-1}. Relative share of work operations showed that loaded and unloaded drive had the largest share, onsie In case of LKT 81T loaded drive was 31% and unloaded drive 25%, while for Timberjack 240A skidder loaded drive accounted for 44% and unloaded drive for 37% of productive work time. Average skidding distance for loaded drive was 1080.34 m for LKT 81T and 727.98 for Timberjack 240A. Unloaded drive, manoeuvring drive and loaded drive showed dependence on corresponding distances. With the increase of the distance and volume of the load, the time required for skidding per unit of product increases. In comparable range (up to 900 m), for the same load size, Timberjack 240A achieved lower standard time, i.e., higher productivity than LKT 81T. Using a skidder at longer distances significantly reduces productivity and increases costs. However, planners often decide in such cases to use a cable skidder for wood skidding, knowing that the costs will be higher, which is again a better option than not harvesting parts of the compartment.

Keywords: skidding; comparison; efficiency; influencing factors

INTRODUCTION

Timber harvesting is a critical part of the wood supply chain, mainly because a wide range of factors in the operational, environmental, technological, labour and institutional sense affects its performance. There is a wide variety of options used for timber extraction, and their choice is often contextual (Borz et al. 2023). Forestry is a very specific economic branch in which it is very difficult to determine the exact efficiency of machinery because various factors influence its work, such as extraction distance, type of soil, terrain slope, weather conditions and many more. Skidding with wheeled skidder is one of the most important timber extraction options used in international practice (Moskalik et al. 2017, Lundbäck et al. 2021). The extraction of forest products from forests is a difficult, risky, expensive, and time-consuming operation, especially in mountainous areas. A prominent issue concerning forest transport is the extraction of forest products without the loss of quality, regarding which the value of log for veneer production and saw logs is usually most considerable. Transport in forestry is usually performed in two stages. The first is called primary transport, which includes all moving of logs or trees, after felling and processing, from the stump to the forest landing site. It is usually carried out by animals, tractors, skidders, forwarders, harvarders, cable yarders or in some cases by helicopters (Marčeta 2019). When extracting timber with cable skidders, the primary transport is divided into two sub-phases. The first sub-phase is winching, and it refers to moving timber from the stump to the skid trail, where the skidder is located, and the second sub-phase is skid trail skidding to the forest landing site.

In the forestry of Bosnia and Herzegovina (BIH), winching and skidding of wood assortments are most often conducted with skidders equipped with a cable winch. They are most applicable because they can handle hilly, mountainous and inaccessible terrain in the compartments that are most common in local forestry areas. In addition, selective and group-selective forest management systems are dominant in high forests in BIH, where the manoeuvring of any type of machinery is strictly limited to the skid trails and skid roads. It is a matter of legal and sub-legal regulations and environmental standards. In most cases, cable skidders are the only applicable technology for the first transportation phase. Recently, the skidder-forwarder combination has been used more and more, in situations when the skidder extracts the wood to the main skid trails, where it is collected by the forwarder and taken further. Many studies have been conducted globally on the issue of wood extraction. Evaluation of the efficiency of timber harvesting and transportation for different forestry equipment and technology is usually carried out using the time study (Björheden et al. 1995), which is conducted in order to express the consumed time and production related to the relevant impact of various factors. From the methodological point of view, there are two types of time studies: correlation studies and comparative studies. Correlation studies are carried out in order to determine the relationship between the work time consumption and factors determining the work, while the aim of comparative studies is to compare the time consumption or productivity of various machines or methods of work used to complete the same task (Mousavi et al. 2013). The time studies of skidders were discussed by many authors in various countries with the aim of determining the impact of various production factors on the productivity and the costs, or with the aim of comparing various skidding methods in different terrain and stand conditions (Proto et al. 2018). Operational and environmental performance assessment in forest operations heavily relies on time studies, whose scope, resolution and extent depend essentially on the available resources (Borz et al. 2023).

Kluender and Stokes (1996) established that grapple skidders are faster and more efficient than cable skidders. However, grapple skidders are not used in Bosnia and Herzegovina. In general, harvest intensity strongly affected grapple skidding productivity, but it affected cable skidding productivity to a lesser extent. This is explained by the fact that grapple skidders had to approach each stem individually, while cable skidders could reach them without moving from the skid trail. Egan and Baumgras (2003) in West Virginia, USA examined the relation among several ground skidding and harvested stand characteristics. They found a direct relation between skidding distance and cycle time, and an inverse relationship between percent of trees removed in the stand and total cycle time. Wang et al. (2004) found that the skidding cycle time was mainly affected by load size and skidding distance.The cost of skidding is typically the most expensive component in the entire tree harvesting process and directly depends on skidding distance (Mitchell 2000).

Most statistical studies on skidding operations indicated that skidding distance, piece size, load volume, winching distance and slope of the trail strongly impact the production of the logging process (Ghaffariyan et al. 2013, Sabo and Poršinsky 2005). Work organisation has a strong impact as well. Zečić and Marenče (2005) examined characteristics of work and efficiency of a work team. They established standard time for two tractors, ranging between 25.05 min·m^{-3} for distance of 150 m and 33.20 min·m^{-3} for distance of 650 m. Allowance time is very important and it consists of delay times necessary for accomplishing the work. Allowance time is determined in order to establish standard times and standard efficiencies and it is added to the effective time in form of allowance time coefficient or in form of absolute value. Coefficients of allowance time for tractors have been established at 1.29 and 1.24. Ghaffariyan et al. (2013) found that skidding time per cycle is a regression function of skidding distance, winching distance, and slope of the trail and piece volume. The average net and gross productions were 18.51 m^3·h^{-1} and 14.51 m^3·h^{-1}, respectively. They found that the productivity of processing, skidding and hauling increased when using the long-log method. Total unit cost of the long-log method in processing, skidding, loading and hauling is lower than in the short-log method (Mousavi 2009). Horvat et al. (2007) examined Ecotrac 120V cable skidder in selective cutting in beech stands and found that the average load volume was 5.34 m^3 and consisted of 5.7 pieces in average, with average length of 7 m and volume of 0.93 m^3. At the hilly working site, the effective time was 8.06 min·m^{-3} and in selective felling the effective time was 9.88 min·m^{-3}. Daily productivity ranging from 57.49 to 35.4 m^3·day^{-1}, at distances varying from 100 to 500 m, can be achieved at hilly working sites. At the mountain working sites, the daily output of 48.53 m^3·day^{-1} to 35.54 m^3·day^{-1} can be achieved for the same distance range (Horvat et al. 2007). The obtained productivity in the previous investigation seems to be very good, compared to 11.6 m^3·h^{-1} achieved by Timberjack 240 C in a mountainous fir stand when skidding very large trees up to 3.9 m^3 (Sabo and Poršinsky 2005). Using the cable skidder LKT 81T in mountain conditions in an 82-year-old fir stand, productivity can reach 7.15 m^3·h^{-1} (Porter and Strawa 2006). Holmes et al. (2002) studied the productivity of a rubber-tire skidder in conventional felling. They showed that the productivity of the skidder was 22.39 m^3·h^{-1}. Behjou et al. (2008) investigated skidding capacity of the wheeled skidder Timberjack 450C in Caspian forests. The skidding cycle time and the travel loaded time as well as cable winching productivity was primarily affected by skidding distances and winching distances. The interaction between skidding distance and the ground slope was another major factor that also influenced elemental times and productivity. The gross and net production rate they achieved were between 20.51 m^3·h^{-1} and 22.93 m^3·h^{-1} for different skidding distances. Zečić (2006) concluded that LKT skidders had satisfactory morphological features, but also outdated technical solutions that emphasized ecological unsuitability in the foreground, and Timberjack 240C type skidders, although highly productive, were oversized for local forest conditions and with incompletely harmonized ergonomic solutions. The investigation of the productivity of skidding using the tree-length method with Timberjack 240C skidder was conducted by Krpan and Zečić (2001). In the final cut, where cutting density was 95.93 $m^3 \cdot ha^{-1}$ and average volume of the felled tree 4.16 m^3, and in the preparatory cutting with cutting density of 54.04 $m^3 \cdot ha^{-1}$ and the average volume of the felled tree of 1.94 m^3, they determined the average load volume of 4.24 m^3 in the final cut and 6.31 m^3 in the preparatory cut. During extraction of wood in two selective stands, with cutting density of 54.2 $m^3 \cdot ha^{-1}$ and 70.0 $m^3 \cdot ha^{-1}$ and average volume of felled trees of 3.2 m^3 and 3.9 m^3, they found that there was no significant difference in the volume of the load and that the share of productive work time in the structure of the total recorded time was approximately the same. According to the results by Zečić (2006), in the preparatory cutting of hardwoods with cutting density of 128.11 $m^3 \cdot ha^{-1}$, average tree volume of 0.52 m^3 and average winching distance of 10.5 m, and in selection cutting with cutting density of 46.05 $m^3 \cdot ha^{-1}$, average volume of felled tree of 1.59 m^3 and average winching distance of 21.8 m, the average load volume of 2.78 m^3 or 5.34 m^3 were achieved with Ecotrac 120V skidder. Different harvesting densities affect the felling site work time consumption, thus also affecting the productivity. Besides the harvesting density, average tree volume has an even greater influence on skidding productivity because it enables the formation of preferred load volume at short winching distances by choking fewer half-stems, often with the use of just one winch drum. Therefore, it can be concluded that the possibility of achieving greatest productivity, in given stand and harvesting conditions, is in the optimal relation between the load size and the felling site work time consumption needed for its forming (Zečić et al. 2019). The additional time does not depend so much on the stand and exploitation factors as on the organization and supervision of the work carried out during the extraction of wood (Zečić et al. 2019). They determined allowance time of 1.22 and 1.31 for Ecotrac 120V skidder in two different work sites. For skidder Ecotrac 120V, Zečić et al. (2019) determined daily productivity of 34.6 and 43.3 $m^3 \cdot day^{-1}$ for skidding distance of 500 m, and average load volume of 3.05 and 3.72 m^3 in two work sites with dominant beech forest. Although skidders are usually intended to use at distances up to 400 m (Pentek et al. 2008, Zečić et al. 2010, Lotfalian et al. 2011, Borz et al. 2014, 2015), in this investigation skidding distance was more than 800 m. In bIH, the use of skidders at longer distance is not unusual. Knezevic at al. (2018) in their investigation recorded loaded skidding distance of Ecotrac 120V up to 1526 m.

Due to the above-mentioned factors, which are different in almost every stand where cutting and skidding is done, ongoing investigations and determination of the most accurate standard times are needed, in order to obtain higher productivity and economy of skidding, which is ultimately one of the objectives of forest management. Different Timberjack and LKT models of skidders are the most common among skidders used in Federation of Bosnia and Herzegovina (Knežević et al. 2018), but similar situation is in the whole BIH. All of the above are the reasons why this paper will investigate the operation of two skidders that are used in selective stands at longer distances.

MATERIALS AND METHODS

Investigation was conducted in the area of two public forest enterprises (Table 1), in compartments 32 (Forest management unit - FMU "Vrbanja") and 99 (FMU "Lješljanica-Maglajska") with similar stand and relief conditions.

General cutting intensity for both compartments was 18%, but because of the real situation in the field in compartments, marked trees were not equally distributed over the area. In compartment 99, assortment structure is such that it is expected to include 52% of saw logs and 23% of other round wood. In compartment 32 it is expected to include 46% of saw logs and 25 other roundwood. For data collection, skid trails were chosen that are similar in terms of the slope of the terrain and the amount of wood that gravitates towards them. Since selection cutting was

Table 1. Research site characteristics.

Forest Company	PFE "Šume Republike Srpske" FA "Vrbanja" Kotor Varoš	PFE "ŠPD-ZDK" Ltd. Zavidovići
Compartment	32; FMU “Uzlomac”	99; FMU "Lješnica-Maglajska"
Inclination	10-15%	15-20%
Altitude	500-1000 m	150-380 m
Soil	Jurassic flysch with islands of limestone and marl	Parapodzolic soil and humus silicate and brown soils
Stand	GK 1103 - High beech forests on acid-brown and ilimerized soils on acid silicate and silicate-carbonate rocks	GK 1105 - Mountain beech forests with predominantly deep eutric cambisol, luvisol, hillside pseudogley and deep colluvium on basic igneous rocks
Area	70.28 ha	26.34 ha

PFE - Public Forestry Enterprise; FA – Forest Administration; FMU – Forest Management Unit made, the structure of the marked trees valid for the entire department may differ significantly from the one related to the part of the compartment where the recording was made. That is why the selection of similar stand conditions was based on the subjective reconnaissance of the terrain.

The subject of the time and work study were two skidders, which are used very often in the forestry of BIH. In compartment 32 LKT 81T skidder was used, while Timberjack 240A skidder was used in compartment 99 (Table 2). Although Timberjack 240A belongs to the group of older skidders, its presence in BIH is still high, and that is the reason it was included in this research. Especially due to the fact that completely repaired versions can be purchased on the BIH market, in which all key parts have been renewed, a new engine has often been inserted and a more modern winch has been installed. There are specialized companies specialized for such repairments.

Recording the work time consumption of skidders was carried out using the methods of snap-back time study, i.e., measuring of the duration of each work operation, and recording the times in recording sheets. The structure of the working time was divided into work operations: Unloaded drive, Manoeuvring drive, Pulling out of cable, Hooking, Winching, Loaded drive, Unhooking and Decking. Delays were divided into technical, personal, and organizational. The assistant measured the distances and volumes of the assortments. Factors whose influence on the work process was examined were chosen based on several previous studies (Horvat et al. 2007, Behjou et al. 2008, Marčeta et al. 2014). The observed factors were driving distance, winching distance, load size, piece size and number of logs per cycle. Work organisation was 1+1, skidder operator and choker-setter. The width of the transport zone was 100 m, i.e. 50 m on both sides of the skid trail, the distance depended on the length of the tail, and all transport cycles on the selected trail were recorded. The assortment harvesting method was carried out. Although the tree-length is recommended for skidders, in Bosnian forestry, it is still common to prescribe the assortment method in harvesting plans.

RESULTS AND DISCUSSION

LKT 81T skidder was used in compartment 32, where 29 cycles were recorded, during which 212 logs were skidded. Total volume of skidded wood was 159.98 m^3 with average volume of 5.52 m^3·load^{-1}. Timberjack 240A was used in compartment 99, where 84 cycles were recorded, with 398 logs. Total skidded wood with Timberjack 240A was 657.34 m^3, with average volume of 7.83 m^3·load^{-1}. Loads consisted of 7.81 logs in average for LKT 81T and 4.74 logs for Timberjack 240A (Table 3).

Table 2. Machinery specifications.

Type	Length (mm)	Width (mm)	Height (mm)	Weight (kg)	Engine	Power (kW)	No of cylinders	Winch type	Cable length (m)
LKT 81T	5600	2260	2990	7145	Martin	74	4	ZTS 2 drums	60
Timberjack 240A	5840	2600	2900	8400	Cummins 4BT	77	4	Gearmatic 1 drum	60

Figure 1. LKT 81T (Photo: M. Đukić).

Figure 2. Timberjack 240A (Photo: S. Handžić).

Table 3. Load parameters.

Skidder	N	Variable	Mean	Sum	Min	Max	Std. Dev.
LKT 81T	29	Pieces per load	7.31	212.00	3.00	11.00	2.280
	29	Volume per piece (m^3)	0.83		0.42	2.27	0.357
	29	Load volume (m^3)	5.52	159.98	3.40	7.60	1.230
Timberjack 240A	84	Pieces per load	4.74	398.00	3.00	7.00	0.906
	84	Volume per piece (m^3)	1.70		0.91	3.25	0.450
	84	Load volume (m^3)	7.83	657.34	4.57	11.27	1.454

Differences in load volume can be explained by differences in the diameter of the cut trees as well as a consequence of subjective decisions when bucking the tree.

Average skidding distance for loaded drive was 1080.34 m for LKT 81T and 727.98 for Timberjack 240A. Distances ranged from 150 to 1880 m for LKT 81T and from 480 to 1000 m for Timberjack 240A (Table 4). These distances are longer than those usually recommended for cable skidders, especially in case of LKT 81T. This was caused by the location of forest roads and forest landing sites in the compartment. Shorter skidding distances are generally preferred as they help to reduce the amount of soil disturbance, minimise the risk of mechanisation damage, and improve the overall efficiency of the skidding (Mousavi et al. 2013), but shorter skidding distances imply better openness with the primary road network, which is again related to large investments and long-term planning. During manoeuvring drive, LKT 81T covers longer distances than Timberjack 240A. The reason for this is that the logs are more concentrated in compartment 32, as well as because their average volume is smaller, so more pieces are needed to form the optimal load.

Relative share of work operations is presented in Figure 3 and it can be seen that loaded and unloaded drive have the largest share. In case of LKT 81T loaded drive is 31% and unloaded drive is 25%, while for Timberjack 240A skidder loaded drive accounts for 44% and unloaded drive for 37% of productive work time. Borz et al. (2023), in comparable research, established that empty and loaded cycle accounted for similar shares in the delay-free skidding time, and their proportions of more than 40% were related to the high skidding distances, where mean distance was 687.2 m.

Orlovský et al. (2020) found that analysing the work operations of the operators of LKT 81T cable skidders, 22.5% of the time was taken by two operations, load skidding and handling the skidder operator, followed by unloaded travel (17%) and load collecting (11.5%), with average 5.06 logs per load and average log volume of 5.43 m^3. Sabo and Poršinsky (2005) confirmed that in the structure of productive work time, felling site work has the largest share on both research sites, 44.60% and 46.40%. Borz et al. (2015) and Borz et al. (2014) established the percentages of non-operation times of 29.3% and 28%. Sabo and Poršinsky (2005) in their study determined a percentage of 32.15% of non-operation time

Table 4. Distance parameters.

Skidder	N	Variable	Mean	Sum	Min	Max	Std. Dev.
LKT 81T	29	Unloaded drive distance (m)	1052.759	30530.00	150.00	1880.00	356.379
	18	Manoeuvring drive distance (m)	149.202	2685.63	12.50	1280.00	292.402
	29	Pulling out the cable distance (m)	29.350	851.15	6.00	56.60	13.372
	29	Winching distance (m)	29.478	854.87	6.00	56.60	13.647
	29	Loaded drive distance (m)	1080.345	31330.00	150.00	1880.00	404.205
Timberjack 240A	84	Unloaded drive distance (m)	730.952	61400.00	460.00	1000.00	159.778
	84	Manoeuvring drive distance (m)	11.964	1005.00	5.00	40.00	6.942
	75	Pulling out the cable distance (m)	21.867	1640.00	0.00	50.00	16.861
	71	Winching distance (m)	22.676	1610.00	5.00	50.00	16.729
	84	Loaded drive distance (m)	727.976	61150.00	480.00	1000.00	162.997

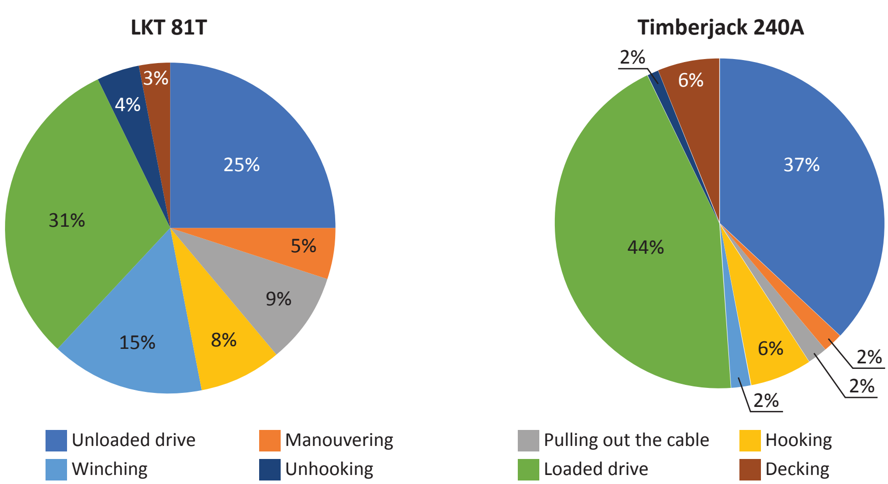

Figure 3. Relative share of work operations in productive work time: **(a)** LKT 81T **(b)** Timberjack 240A.

for the Timberjack 240C cable skidder. Due to the very diverse stand and terrain conditions in the forest (tree mixture, stand density, operation and relief characteristics), the results of the time study and the obtained models are applicable only in the situations with the same or similar work conditions (Mousavi et al. 2012, Marčeta 2019).

In order to examine whether the skidder type, distance and load volume have a statistically significant influence on the effective time per cycle, multiple regression with dummy variables was performed. The result showed that skidding distance, skidder type and load volume had a statistically significant influence ($p<0.05$) (Table 5). This result indicates that all future analyses in this research have to be conducted separately for each skidder.

The analysis of partial correlations showed that distance has a significantly greater influence than other parameters (Table 6).

Analysis of variance showed very strong reliability of regression model (Table 7).

The impact of factors on the duration of each recorded work operation was examined by regression analysis, where factors were independent variables and work operations were dependent variables. Determination of factors for regression was based on whether dependence is expected to be shown or not, and on the previous studies (Marčeta et al. 2014; Kulak et al. 2017, Knezevic et al. 2018). In the cases when dependence was proven, mathematical model was established, and when there was no statistically significant dependence, the average operation time was taken into further calculations. It can be seen in Table 8 that Unloaded drive, Manoeuvring drive and Loaded drive showed dependence on corresponding distances. The mathematical models represented quadratic or linear equation. The situation was similar for both skidders. The work operation Unloaded drive showed significant dependence on distance (Table 8), which is in accordance with other studies (Wang et al. 2004, Nurminen et al. 2006, Mousavi et al. 2012, Mousavi et al. 2013, Marčeta et al. 2014). The work operation Pulling out the cable was affected only by distance, which was also stated in the studies by Marčeta et al. (2014) and Borz et al. (2014). Mousavi (2012) showed in case of a cable skidder whose time consumption for collecting showed statistically significant dependence on the number of logs. Najafi et al. (2007) conducted a time study focused on HSM-904 skidder, and found out that the skidding time depends on the skidding distance and the number of logs in the load. Lotfalian et al. (2011) established in their study that skidding time depends on the skidding distance and the slope inclination. The present study determined the skidding distance and load volume as statistically significant variables affecting the time consumption of skidding with cable skidders. These results are in accordance with the results presented in the study by Marčeta et al. (2014). Also, the research by Orlovský et al. (2020) shows that the number of logs in the load and load volume are statistically significant factors affecting the time consumption of this operation with the cable-grapple

Table 5. Multiple regression with dummy variables.

N = 113	**Regression summary for dependent variable: min·cycle^{-1}** R=0.85; R^2=0.72; F(3,109)=97.25; p<0.0000; Std. Error of estimate: 7.1485					
	b*	**Std. Err. of b***	**b**	**Std. Err. of b**	**t(54)**	**p**
Intercept			22.02714	5.599766	3.93358	0.000148
Skidder type	0.192629	0.067146	5.93712	2.069550	2.86880	0.004949
Skidding distance	0.647458	0.059621	0.03013	0.002775	10.85965	0.000000
Load volume	-0.152456	0.062383	-1.19561	0.489233	-2.44386	0.016135

Table 6. Partial correlations.

Variable	b* in	Partial	Semipart	Tolerance	R-square	t(109)	p-value
Skidder type	0.192629	0.264960	0.143304	0.553444	0.446556	2.86880	0.004949
Skidding distance	0.647458	0.720888	0.542467	0.701978	0.298022	10.85965	0.000000
Load volume	-0.152456	-0.227918	-0.122077	0.641178	0.358822	-2.44386	0.016135

Table 7. Analysis of variance for effective cycle time.

Effect	**ANOVA; min·cycle^{-1}**				
	Sum. of Squares	df	Mean Squares	F	p-value
Regress.	14909.05	3	4969.684	97.25329	0.000000
Residual	5569.95	109	51.100		
Total	20479.00				

skidders. In the case of cable skidders, only the number of logs in the load affects the time consumption of unhooking the load (Orlovský et al. 2020).

The time studies by Mousavi et al. (2013) and Proto et al. (2018) did not prove any of the studied independent variables to be statistically relevant concerning the time consumption of unhooking the load. Wang et al. (2004) found out that the time consumption of unhooking the load depends on the log diameter, mean merchantable height and the number of logs in the load. Proto et al. (2018) confirmed the dependence of the overall work cycle time of the John Deere 548H cable-grapple skidder on the skidding distance and load volume.

The overall work cycle time of the studied cable skidders is affected mostly by the skidding distance, number of logs in the load and the load volume, which was proven to have the least impact (Orlovský et al. 2020), which is in accordance with results of this research. Ghaffariyan et al. (2013) also demonstrated the dependence of the overall work cycle time of the skidding distance, winching distance, inclination of the skidding trail and load volume. Behjou et al. (2008) confirmed in their research studies the dependence of the overall work cycle time of Timberjack 450C skidder on the skidding distance, winching distance and interaction between the skidding distance and skidding trail inclination.

Standard time was calculated in the way that time for each work operation was calculated with regression equation for cases where significant dependence of influencing factors was established, or using the average values if there was no dependence. The sum of work operation time was multiplied with allowance time coefficient and divided with the volume of skidded load. Productivity was an inverse value, adjusted to 8-hour working day. Corresponding coefficients of allowance time in this study were 1.13 for LKT 81T and 1.18 for Timberjack 240A. These coefficients were obtained empirically during field data collection. However, the definition of the allowance time factor is always a subject of doubt because there are many influencing factors. The higher the number of recordings, the more likely the allowance time will be credibly captured. This again contradicts the economics of conducting labor studies. A compromise is needed when combining data from own and other studies.

In Figure 4, comparative standard time for different skidding distances and load sizes, and winching distance of 30 m are presented. It ranges from 100 m to 1000 and up to 1500 meters, in accordance with the distances recorded in the field for both machines. With the increase of the distance and volume of the load, the time required for skidding per unit of product increased. It can be seen that in comparable range (up to 900 m), for the same load size, Timberjack 240A achieved lower standard time, i.e., higher productivity than LKT 81T. Productivity of skidders based on distance and load volume per 8-hour working day ($m^3 \cdot day^{-1}$) is presented in Figure 5. These results are in line with expectations, based on the opinions of machine operators and previous research. Orlovský et al. (2020) found that the mean gross production of LKT 81T cable skidders considering the type of the forest stand, mean skidding distance and the type of the skidder ranged from 3.38 $m^3 \cdot h^{-1}$ to 5.97 $m^3 \cdot h^{-1}$. Porter and Strawa (2006) in their study established a mean gross production of the LKT 81T skidder of 7.15 $m^3 \cdot h^{-1}$ in an 82-year-old fir stand.

The productivity obtained in this research is comparable to the results of similar studies, and similar influencing factors were also isolated. Borz et al. (2023) evidenced that for cutting intensities in the range from 7 to 15 $m^3 \cdot ha^{-1}$, productivity of skidding operations in mature broadleaved forests depended heavily on the extraction distance. Taking

Table 8. Time dependence analysis.

	Work operation	N	Independent variable	Model	R^2	R	p
LKT 81T	Unloaded drive (min)	29	Unloaded drive distance (m) - x_1	y = 3.9288 + 0.0104x	0.61	0.78	0.000
	Manoeuvring drive (min)	18	Manoeuvring drive distance (m) -x_2	y = 2.2941 + 0.0137x	0.80	0.89	0.000
	Pulling out of cable (min)	29	Pulling out the cable distance (m)	y = 1.5323 + 0.1224x	0.30	0.55	0.001
	Hooking	29	Piece volume (m^3)	4.93 $min \cdot cycle^{-1}$	no significance		
	Winching (min)	29	Winching distance (m)	y = 0.7481 + 0.2764x	0.27	0.51	0.004
	Loaded drive (min)	29	Loaded drive distance (m) -x_3	y = 3.808 + 0.0138x	0.55	0.74	0.000
	Unhooking (min)	29	Load volume (m^3)	2.67 $min \cdot cycle^{-1}$	no significance		
	Decking (min)	18	Load volume (m^3)	2.40 $min \cdot cycle^{-1}$	no significance		
Timberjack 240A	Unloaded drive (min)	84	Unloaded drive distance (m) -x_1	y= 0.557+0.0211x	0.97	0.98	0.000
	Manoeuvring drive (min)	84	Manoeuvring drive distance (m) -x_2	y= 0.1356+0.0574x	0.86	0.87	0.000
	Pulling out of cable (min)	80	Pulling out the cable distance (m) -x_3	y = 0.3586+0.0192x	0.59	0.77	0.000
	Hooking	84	Piece volume (m^3)	2.67 $min \cdot cycle^{-1}$	no significance		
	Winching (min)	79	Winching (m)	y = 0.3211+0.0251x	0.70	0.83	0.000
	Loaded drive (min)	84	Loaded drive distance (m) - x_4	y = 14.2656-0.0162x+2.963E-5x^2	0.96	0.98	0.000
	Unhooking (min)	84	Load volume (m^3)	0.55 $min \cdot cycle^{-1}$	no significance		
	Decking (min)	65	Load volume (m^3)	3.05 $min \cdot cycle^{-1}$	no significance		

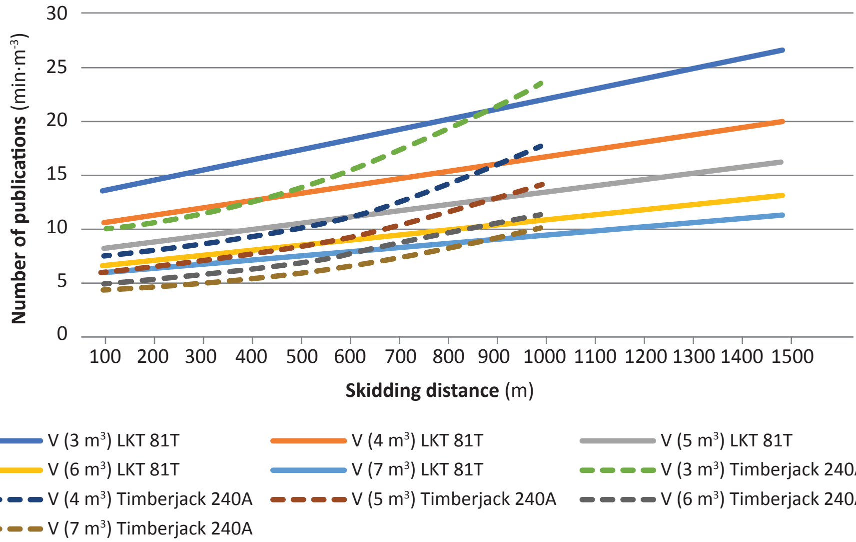

Figure 4. Standard time (winching distance - 30 m).

as a reference an extraction distance of 200 m, productivity reduced twice at 800 m, and decreased to one fourth at 2000 m. For a distance of 900 m, Borz et al. (2023a) simulated productivity of 8.8 $m^3 \cdot h^{-1}$ with TAF skidder in a broadleaved forest of low cutting intensity. Knežević et al. (2018) investigated the productivity of Ecotrac 120V skidder and recorded the total work time of 58.47%. The average unloaded travel distance in this study was 585.26 m, loaded travel distance was 490.49 m, winching distance 16.83 m, number of pieces in the load 5.95, the volume of the load 5.17 m^3 and the average volume of the piece in the load 1.02 m^3. The standard time for skidding was 6.57 $min \cdot m^{-3}$ at a skidding distance of 100 m, i.e. 17.60 $min \cdot m^{-3}$ at a skidding distance of 1500 m. The daily skidding productivity ranged from 73.07 $m^3 \cdot day^{-1}$ at a skidding distance of 100 m to 27.28 $m^3 \cdot day^{-1}$ at a skidding distance of 1500 m. Marčeta et al. (2014) established that daily skidding productivity of LKT 81T skidder ranged from 42.29 $m^3 \cdot day^{-1}$ for a load volume of 2.80 m^3 in the assortment method to 83.64 $m^3 \cdot day^{-1}$ for a load volume of 6.62 m^3 in the half-tree length method, for skidding distance of 250 m. Knežević et al. (2018) established productivity ranges from 73.07 $m^3 \cdot day^{-1}$ at a skidding distance of 100 m to 27.28 $m^3 \cdot day^{-1}$ at a skidding distance of 1.500 m. Zečić (2006) determined that the daily productivity of Ecotrac 120V ranged from 50.53 $m^3 \cdot day^{-1}$ at a skidding distance of 50 m to 35.54 $m^3 \cdot day^{-1}$ at a skidding distance of 500 m.

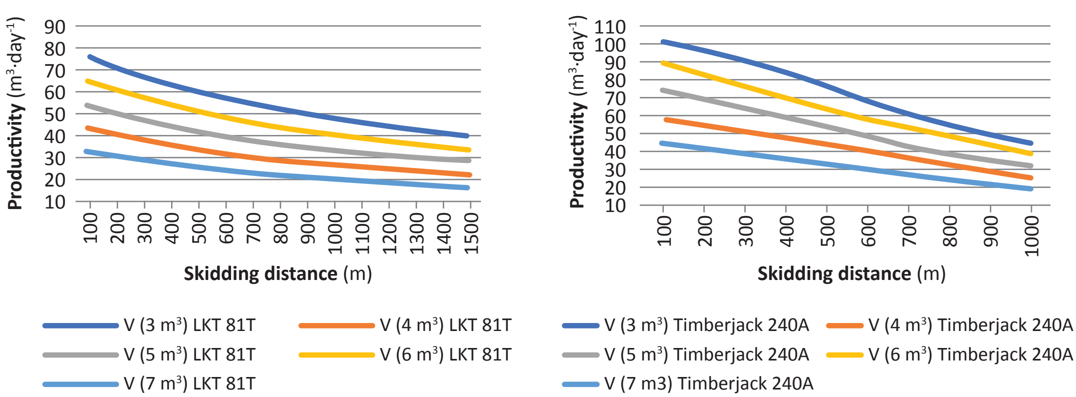

Figure 5. Productivity of skidders based on distance and load size (winching distance - 30 m): **(a)** LKT 81T; **(b)** Timberjack 240A.

CONCLUSIONS

Although there is an important body of knowledge on the performance of skidding operations by dedicated machines, from the current perspective, most of the studies supporting it were conducted on obsolete equipment, which may present a limitation in their applicability since significant improvements were developed in relation to the capabilities of the latest generation machines. For instance, developments in engines, transmission systems, and ergonomics have contributed significantly to the improvement of operational and environmental performance (Borz et al. 2023). In many countries, such as in BIH, the purchase of new, modern machines is more an exception than a rule, and most of the work is conducted with machines that are a decade or more old. It will remain this way for a long time, so research with relatively older machines makes a lot of sense. The density of the transport network determines the skidding distances. Often the forest truck road does not reach the depth of the compartment, which increases hauling distances and costs. However, planners often decide in such cases to use a cable skidder for the first phase of transport, knowing that the costs will be higher, which is again a better option than not harvesting parts of the compartment. However, they work with a selective management system where each felling is also a silvicultural measure. If they waited for the truck road to be built, it could take a long time and management plans would not be fulfilled. An excellent option in such cases is the use of forwarders that can handle longer distances, up to 1000 m, than classic cable skidders. Forwarders have appeared in forestry in BIH in recent years, but their use is still not widespread. In order to encourage use, certain regulations defining the movement of vehicles through the forest, as well as management systems, should be modified.

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DM conceptualized the study, analysed data and wrote the paper, SH collected field and office data, prepared data for analysis, MĐ collected field and office data, prepared data for analysis; VP statistical analysis.

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Conflicts of Interest

The authors declare no conflict of interest.

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