DOI: 10.2478/frp-2019-0020
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Wrzesień / September 2019, Vol. 80 (3): 219–226

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Evaluating the suitability of machinery use during skidding of wood in pine stands

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Abstract. Skidding of large-sized logs requires special machinery such as skidders, clambunks, forwarders or farm tractors with a winch or hydraulic tongs. The precise choice of which skidding machine to use depends largely on the desired efficiency and economic factors. The aim of this research was to evaluate the suitability of three different machines (LKT 81 skidder, John Deere 1110D forwarder and Pronar 1221A agricultural tractor with hydraulic tongs) for wood skidding based on technical and economic indicators. The practical work for this research was carried out in the Mirosławiec Forest Division in areas with fresh mixed coniferous forest habitats where the dominant species in the stands was pine and strip-like clear cutting was the preferred management practice.

The best machinery performance values were obtained for skidding using the John Deere forwarder.

Keywords: coniferous logs, skidding, efficiency

1. Introduction

Skidding comprises the first transportation step in the logging process and consists of moving the harvested wood from the felling location to the nearest transitional depot, from where it is transported to the destination points (Dudek, 2010a; Maciak and Popczyński, 2019; Sosnowski, 2003). Depending on the terrain, silvicultural and nature protection conditions, as well as the length and thickness of the individual wood loads, agricultural tractors are used for skidding with additional equipment, which are adapted for operations in the forest environment (Chmielewski and Porter, 2012; Dudek, 2009, 2011; Jabłoński and Stempski, 2015; Kulak et al., 2013; Poje et al., 2016; Porter and Strawa, 2006; Sosnowski and Porczak, 2005; Sowa and Kulak, 2008; Sowa and Szewczyk 2005, 2010), or else specialised forest machines, cable cars and horses (Dudek, 2012).

The use of an agricultural tractor for skidding depends on its accessories. Skidding ropes or chains are quite often used, wherein the skidding process includes dragging a part of wood load on the ground, which results in a considerable damage to the forest cover (Jodłowski, 2009a).

The machines used for semi-suspended skidding are, among others, cable skidders, grapple skidders, clambunks and agricultural tractors equipped with winches or hydraulic tongs. For long logs, forwarders are used with hydraulic tongs mounted on the back frame. Forwarders not equipped with specialised hydraulic tongs are also used, wherein the wood is loaded onto the tractor loading space and held by a hydraulic crane during transport. The cable skidders are specialised heavy vehicles designed for skidding entire tree trunks or long logs, which are used during tree felling operations and late thinnings (Jodłowski, 2009b).

Currently, in European countries, the main means of transporting timber to logging roads are forwarders (Byblyuk and Byblyuk, 2007). In timber-harvesting companies, forwarders constitute the essential equipment in the cut to length (CTL) system (Jodłowski, 2010). High load capacity and traction parameters let limiting the number of passages through forested areas and combine skidding with transport (Stempski, 2007).

The selection of an appropriate set of machines along with adjustment of the chosen technology to forest stand and the terrain characteristics are essential to guarantee high effectiveness of the activities undertaken (Maksymiak and Grieger, 2008).

Assessments of labour intensity in specific technological solutions should always include evaluation of the business day structure. This enables recognition of inconsistency drivers, as well as provides the possibility to qualitatively assess factors

Received: 28.02.2019 r., accepted after revision: 25.08.2019 r.

that shape labour consumption levels. Such an analysis, based on identified technical solutions and carried out with a reference to time consumption in presently functioning solutions, enables work optimisation and construction of appropriate technological processes (Szewczyk and Stańczykiewicz, 2012).

The aim of the study was to determine and compare the basic technical and economic indicators used to assess labour of skidding means used in Scots pine forest stands growing in fresh mixed coniferous forest sites.

2. Materials and methods

The study plots (I–III) were established in the forest district Mirosławiec, within fresh mixed coniferous forest sites (BMśw), in the stands with Scots pine as the dominant species, managed for clear cutting type IB (Table 1). Large -sized raw material was produced in the form of long logs. The characteristics of the processes of wood harvesting and skidding used on individual plots are as follows:

Plot no. I

The process of harvesting and skidding was carried out at a manual–machine level of technology in the long wood system (LWS). The following technological operations were identified:

- felling, delimbing and cutting off the tree top with a chainsaw;
- skidding of the entire trunk with the skidder LKT 81;
- dividing felled tree into parts with specific qualitative and dimensional characteristics;
- skidding (average distance 100 m) of divided logs to landing with the use of the skidder LKT 81 and
- timber stacking.

Five workers were employed to fulfill the above tasks. Two workers cut down and delimbed trees within the working area and one worker operated the LKT 81 skidder. Two workers dealt with dividing the felled tree into parts (on a handling table) and stacked short timber assortments (S2a, S2b, S4).

Plot no. II

The process of harvesting and skidding was carried out at a manual–machine level of the tree length system (TLS). The following technological operations were identified:

- felling, delimbing and dividing the felled tree into parts using a saw;
- stacking short wood packages on the working area;
- short log skidding using a tractor with a trailer,
- long log skidding (average distance 100 m) with the agricultural tractor Pronar 1221A equipped with hydraulic tongs and
- timber stacking using the tractor.

After tree felling, timber assortments were produced on the working area, and then the tractor was used for skidding long, large-sized logs.

Plot no. III

The process of harvesting and skidding was carried out at a semi-automatic level of the TLS. The following operations were identified:

- felling, delimbing and dividing trees into parts using a harvester and
- skidding (average distance 200 m) with the forwarder John Deere 1110D.

The harvester produced long logs and short, medium-sized timber assortment (S2a, S4). The forwarder picked long logs within the standard loading space. The long logs were loaded onto the loading box, and then the log back ends were dragged along. During skidding, the operator made sure that the lowest (thickest) parts of the trunks were supported by a hydraulic crane.

Assessment of the labour time of the skidding machinery was carried out in accordance with the standard BN-76/9195-01. The following technical–economic indicators were determined: effective productivity, operational effectiveness, effectiveness during shift working time, effectiveness during the overall shift time and the control shift time, technical certainty coefficient, technological certainty coefficient, coefficient of working time utilisation, coefficient of the overall shift time utilisation, and also, labour intensity in the effective time, as well as in the shift operation and work times and during the control shift time (Laurow, 1999, after Botwin, 1993).

The effective time was divided into the following categories:

$T_{1Ł}$ – the time within which the machine was loading wood and moving on the working area;

T_{1Z} – the time for picking wood pieces;

$T_{1JŁ}$ – the time of driving with wood load from the working area to the wood storage or division sites;T_{1R} – the time of wood unloading using a hydraulic crane;

T_{1O} – the time of wood detaching to make piles;

T_{1P} – the time within which the machine was driving with wood from its division site to the site where wood piles were made and

T_{1M} – the time for making wood piles.

In the case of supplementary time needed for research purposes, the following were identified:

T_{22} – the time of running on empty, when the skidding means moved back and forth between the sites of wood unloading, dividing and reloading (skidder, forwarder, agricultural tractor) and

T_{23S} – the time of wood dividing (skidder).

Table 1. Stand characteristics of research areas

Area number / Location	Area [ha]	Forest site type	Stocking	Canopy density	Species share	Age [years]	Site Index	DBH [cm]	Height [m]	Stand volume [m^3/ha]
I / Hanki, 461c	1,80	BMśw	1,0	broken	10 So	110	II	40	24	389
II / Mirosławiec, 25g	2,40	BMśw	0,7	broken	8 So	100	II	38	26	219
					1 Św	100	III	43	25	42
					1 Św	60	II	22	19	31
III / Mirosławiec, 46b	2,17	BMśw	0,9	broken	10 So	90	I	35	26	381

Explanation: BMśw – fresh mixed coniferous, So – Scots pine, Św – Norway spruce

The examined skidding means performed the following work cycles:

Skidder LKT 81

- running on empty to the sites where the wood pieces were collected (clamped);
- grabbing the wood pieces;
- travelling with wood load to the raw material handling site (wood division);
- waiting at the handling table for the time of wood dividing with the use of a saw;
- driving from the handling table to the wood storage area;
- leaving the wood pieces at the site where wood piles were made and
- making wood piles.

Agricultural tractor Pronar 1221A equipped with hydraulic tongs

- running on empty to the sites where the wood pieces were collected;
- grabbing the wood pieces;
- travelling with wood load to the wood storage area;
- leaving the wood pieces at the site where wood piles were made and
- making wood piles.

Forwarder John Deere 1110D

- running on empty to the sites where the wood pieces were collected;
- wood loading during moving within the wood division area;
- travelling with wood load to the wood storage area and
- wood unloading.

3. Results

Within the three research plots (I–III), 62.28, 61.35 and 103.75 m^3 of wood was collected, respectively. In the case of the skidder LKT 81, large-sized wood skidding comprised 21 cycles. The skidder picked from three to eight wood pieces at a time. The average thickness of the load in one cycle was 2.97 m^3. The effective active time (T_1) accounted for 67% of the working shift time (Table 2). Time losses due to reasons beyond the control of the skidder (T_8) were caused by work interruptions due to tree suspension (three events) and standby at the wood handling table (one event).

In the case of skidding using the agricultural tractor Pronar 1221A, 44 cycles were performed. The tractor picked two wood pieces in one cycle. The average thickness of the load was 1.39 m^3. The effective active time (T_1) accounted for 61% of the working shift time. The fault clearance time (T_4) and the rest time (T_5) accounted for 1% and 7% of the control shift time, respectively. In the case of the agricultural tractor, time losses (T_8) due to uncontrollable factors were not evidenced.

Skidding carried out using the forwarder John Deere 1110D included 15 cycles. The average thickness of the picked load was 6.92 m^3. The effective active time (T_1) accounted for 77% of the working shift time. The supplementary time (T_2), that is, the time of running on empty from the wood storage site to the wood loading site accounted for 23% of the time T_{04}. Time losses due to reasons beyond the control of the tested machine ($T_8 = 2\%$) resulted from taking a break by the forwarder operator to confirm the arrangements with the responsible forester and the time spent on cutting off the knots remaining on the logs (three events).

In all the time categories identified, the forwarder (JD 1110D) showed the highest values of performance parameters when compared with the other skidding means tested (Table 3).

The obtained values of technical and technological certainty coefficients for all the examined skidding means were close to or equal to 1. Skidding with the tractor Pronar 1221A showed comparatively the highest value of labour intensity in all the time categories identified.

Table 2. Values of individual work time categories for the analyzed skidding machines

Work time categorie	Skider LKT 81	Pronar 1221A agricultural tractor with hydraulic tongs	Forwarder John Deere 1110D
Effective active time T_1, min[1]	169.17	220.37	245.45
$T_{1Ł}$, min	-	-	85.48
T_{1JL}, min	42.77	166.32	67.87
T_{1R}, min	-	-	92.10
T_{1P}, min	8.62	-	-
T_{1M}, min	31.67	27.12	-
T_{1Z}, min	73.03	22.20	-
T_{1O}, min	13.08	4.73	-
Subsidiary time T_2, min[2]	76.70	136.13	73.57
T_{22}, min	41.23	136.13	73.57
T_{23S}, min	35.47	-	-
Faults deletion time T_4, min	**4.33**	**1.82**	-
T_{41}, min[3]	4.33	1.82	-
Rest time T_5, min	50.48	27.88	46.73
Losses of time due to reasons independent of the researched machine, min	**13.83**	-	8.65
T_{81}, min[4]	13.83	-	8.65

[1] $T_1=T_{1Ł}+T_{1JL}+T_{1R}+T_{1P}+T_{1M}+T_{1Z}+T_{1O}$; $T_{1Ł}$ – the time, within which machine was loading wood, moving on working area; T_{1JL} – the load drive time from stump area to wood storage place other bucking place; T_{1R} – the time of wood unloading using hydraulic crane; T_{1P} – the time, within which machine was driving with wood from bucking place to pile of wood; T_{1M} – lay in a pile of wood time; T_{1Z} – the time of wood pieces catching; T_{1O} – uncoupling time in lay in a pile of wood place

[2] $T_2=T_{22}+T_{23S}$; T_{22} – waste drive time from wood unloading place to loading place; T_{23S} – the time of wood bucking
[3] T_{41} – technological faults deletion time
[4] T_{81} – losses of time from organizational reasons

4. Discussion

In Poland, the economic effectiveness of the solutions used in forestry operations has been especially important since establishing privately owned forestry companies in the early 1990s. Consequently, the effectiveness assessed at individual workplaces has become essential (Sowa et al., 2007).

The productivity is expressed as the size of the product (service rendered) per unit time (Glazar and Wojtkowiak, 2009). The time encompasses not only one category, but also consists of many components that create a working shift. The more widely the time of the product creation is considered (the effective time, operational time, etc.), the more objective is the assessment of a given technology (Sowa et al., 2007).

In forestry operations, the condition for achieving high performance is, among others, selection of appropriate technical means, fitting forest stand and terrain characteristics, as well as applicable techniques of wood cutting, stacking or leaving behind certain wood assortments on tree felling areas (Maksymiak and Grygier, 2008; Suwała, 2002).

In the present study, the research plots selected were similar in terms of terrain conditions. The areas were slightly hilly with no barriers that could possibly hinder wood skidding.

Table 3. The basic technical and economic indicators of the analyzed skidding machines

Indicator / Unit	Skider LKT 81	Pronar 1221A agricultural tractor with hydraulic tongs	Forwarder John Deere 1110D
Effective active time T_1/h, min	2.81	3.67	4.09
Operative active time T_{02}, min	4.10	5.94	5.32
Working shift time T_{04}, min	4.17	5.97	5.32
Total shift time T_{07}, min	5.01	6.44	6.24
Control shift time T_{08}, min	5.24	6.44	6.38
Effective efficiency W_1/$m^3 \cdot h^{-1}$	22.16	16.71	25.37
Operational efficiency W_{02}/$m^3 \cdot h^{-1}$	15.19	10.33	19.50
Efficiency in working shift time W_{04}/$m^3 \cdot h^{-1}$	14.93	10.28	19.50
Efficiency in total shift time W_{07}/$m^3 \cdot h^{-1}$	12.43	9.53	16.63
Efficiency in control shift time W_{08}/$m^3 \cdot h^{-1}$	11.88	9.53	16.26
Technological robustness coefficient K_{41}	0.98	1.00	1.00
Technical robustness coefficient K_{42}	1.00	1.00	1.00
Working shift time use coefficient K_{04}	0.67	0.61	0.77
Total shift time use coefficient K_{07}	0.56	0.57	0.65
Effective labour consumption P_1/$h \cdot m^{-3}$	0.045	0.060	0.039
Operative labour consumption P_{02}/$h \cdot m^{-3}$	0.066	0.097	0.051
Labour consumption in working shift time P_{04}/$h \cdot m^{-3}$	0.067	0.097	0.051
Labour consumption in total shift time P_{07}/$h \cdot m^{-3}$	0.080	0.105	0.060
Labour consumption in control shift time P_{08}/$h \cdot m^{-3}$	0.084	0.0105	0.061

The obtained results draw attention to the size of wood logs picked by the examined skidding means. The agricultural tractor Pronar 1221A equipped with hydraulic tongs was able to move around two logs (sometimes one) at a time, whereas the LKT 81 skidder picked several logs (from three to eight). In this case, the average load thickness in one skidding cycle was 2.97 m^3, which corresponds with the results reported by Grieger et al. (2016). The forwarder JD 1110D loaded comparatively the highest number of logs, and this resulted in the fact that it made the smallest number of trips. The average skidding distance was 200 m on plot no. III, which is twice as long as those on plots no. I and II (100 m); nevertheless, the forwarder achieved the highest efficiency when compared to that of other skidding means examined under the conditions of the present study. As reported by Suwała and Rzadkowski (2001), in comparison with a skidder, the difference in work efficiency in favour of a forwarder clearly increases with an increasing skidding distance.

In order to make the most of the space for storing raw wood material, both the skidder LKT and the tractor Pronar 1221A were stacking the logs using a decking blade. The time needed for making wood piles was 32 and 27 min, respectively. The forwarder JD 1110D did not perform such activities due to its technical structure. Wood raw material was moved to a pile by means of the hydraulic clamps. After arranging the thickest trunk section, the operator often corrected the position of the log rear part, then grabbed it and placed on the pile. The time for these activities was classified in the category unloading wood. When stacking logs with a hydraulic crane in high piles, the available space for storing wood was maximised, which undoubtedly had an effect on the overall value of skidding effectiveness. In the absence of space for storing wood, the operator is forced to transport wood over increasing distances.

Important information is that the forwarder examined in this study was not equipped to operate long logs. Without changing the equipment setup (converting), the machine forwarded long logs first and then short logs.

For organisational and economic reasons, the possibility of using forwarders for long log skidding is very important from the point of view of machine owners (Grodecki and Stempski, 2002). However, it should be remembered that skidding should be carried out in accordance with the health and safety regulations, using appropriate equipment – using tractors adapted to semi-suspended timber skidding in the case of long log skidding (Domżalska, 2016). According to Grodecki and Stempski (2002), converting the machine to the clumbank version expands the scope of works that can be carried out. The use of non-converted machinery can lead to accelerated wear of vehicle structural components.

In practice, machines used for long log skidding are usually those that are not converted.

According to Grodecki and Stempski (2002), long log skidding with a forwarder in the clambunk version at smaller distances (up to 100 m) was characterised by higher effectiveness compared to short log skidding carried out with a forwarder designed for long or short logs or crosscut logs. Above a distance of 300 m, the effectiveness achieved by a clumbank skidding long logs was much lower, and this difference widened as the distance increased.

A detailed analysis of individual work time categories can contribute to the optimisation of the work processes. The share of work time categories during the work shift and methodology of classification of the activities are important in assessing effectiveness.

According to the results of Durek and Gendek (2016), the operational time is the real time of machine operation and it can include the duration of all technological operations. In the case of a forwarder, it is the time of trip from the timber yard established nearby the cutting area to the first collection of raw wood material, the time of crane operation during wood loading, the time of trips between consecutive wood piles, the time of trip with wood load from the wood division area to the wood storage area and the time of wood unloading. These time periods depend on technical parameters of the machine, the tasks performed, and the natural and forest conditions in a given area.

The operational work time usually amounts to 70% of the entire work shift (Glazar and Wojtkowiak, 2009).

In the case of the technical measures analysed, the ratio of the operational time to the control shift time was 78% for the skidder, 92% for the agricultural tractor and 83% for the forwarder. The coefficients of utilisation of the shift work time (K_{04}) and the overall shift time (K_{07}) were 0.67 and 0.56, respectively, for the skidder, 0.61 and 0.57, respectively, for the agricultural tractor and 0.77 and 0.65, respectively, for the forwarder.

In the 95-year-old Scots pine stand, in the case of skidding by means of a harwarder, the ratio of operational time to the control shift time was 79%. The coefficients of utilisation of the shift work time (K_{04}) and the overall shift time (K_{07}) were slightly higher when compared to skidding with a forwarder, and amounted to 0.79 and 0.73, respectively (Glazar and Maciejewska, 2008).

During the tests carried out under the conditions of the present study, the highest performance values in all time categories identified were achieved in the case of skidding using the forwarder JD 1110D.

Proper estimation of time-consuming levels is a key issue for both service providers (allows for rational pricing of services) and payers (allows for establishing realistic prices and eliminating discounted offers) (Szewczyk et al., 2013).

In clear-cut areas of Scots pine stands with large thickness, the short-wood method was proposed (using the harvester and forwarder); the long-wood method including felling, delimbing and dividing was carried out with the harvester, in addition to log skidding carried out with the skidder or the forwarder (for shorter logs), especially at small distances (Suwała and Jodłowski, 2002).

For higher value timber assortments, the harvester can be replaced with a saw.

The effectiveness of skidding improves with increasing the average log thickness and decreasing the stand density within the felling areas, which facilitate the movement of skidding means (Dudek, 2010b).

The works associated with wood harvesting and skidding are one of the most labour intensive (Szewczyk et al., 2013), but the machines currently used in these processes achieve very high operational efficiency (Długosiewicz and Grzebieniowski, 2009; Maksymiak and Grygier, 2008; Walsh and Strangard, 2014).

In recent years, a boost in specialised equipment for forestry works has been observed. This is a signal of rapid changes taking place in the technologies of wood harvesting and skidding, as well as in the organisation of works in the companies providing forestry services. The changes are forced by both situation on the national labour market and migration to other countries in search for better-paid jobs. Ecological and quality requirements for wood raw material also play a role in these processes. Political and economic changes that took place in Poland after 1989 resulted in rapid changes in rural areas. Wherever work requires a lot of energy and physical effort, a growing shortage of manpower has been observed. In modern times, hard physical work is not attractive for young people. In Poland, every third forestry company is short of employees (Nowacka, 2009).

5. Conclusions

For all the work time categories examined, forwarder skidding was characterised by the highest performance values. Despite the favourable results when compared with other skidding means tested, it should be kept in mind that the tested forwarder employed for skidding long logs was not adapted for this kind of forestry operation. Therefore, the present results should not be perceived as a recommendation for using the method described in practice.

Long log skidding using the skidder proved to be more efficient when compared to skidding using agricultural tractor equipped with hydraulic tongs.

Conflict of interest

The authors declare no potential conflicts.

Acknowledgement and source of funding

The research was financed by own resources.

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Authors' contributions

K. Sz. – manuscript concept, literature review, methodology, preparation of the results, discussion – 50%, manuscript writing – 100%;

P. I. – manuscript concept, literature review, methodology, preparation of the results, discussion – 50%, field work – 100%.