TIME CONSUMPTION OF SKIDDING IN MATURE STANDS PERFORMED BY MEANS OF WINCHES AGGREGATED WITH FARM TRACTOR

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Abstract: *The aim of the present research was to determine the models of characteristics of the time consumption in skidding performed with the use of a winch in pine, fir, spruce and beech mature stands. The research covered the operation of skidding from the stand to the skidding trail at the distance of up to 50 m. A time study was performed for skidding operations, the volume of timber and the intensity of thinning schedule. The average time consumption of skidding in the operational time, assessed in the examined mature stands, amounted to approximately 18 min/m³. Significant differences were observed in the levels of time consumption between early thinnings (24 min/m³) and the late ones (13 min/m³). The operational time structure for skidding with use of winches was characterized by a large share of auxiliary time: 71%, of which 30% was used for load attachment and detachment and 36% for transfer. Approximation was also done of the multiple regression equation, describing the changes in the level of skidding time consumption – the Empirical Efficiency Index (EST) – depending on environmental factors (stand, cutting category), elements of the working day structure (the share of a given time category in a shift) and task intensity (ratio of the number of harvested trees per area unit). The strongest connections between EST and the analyzed variables were noted for the factors related to the percentage of time of load attachment and detachment and task intensity.*

1. Introduction

The market economy, which in the mid-1990s led to the privatization of almost 100% of felling work in Poland (Więsik, 2000), has entirely changed the idea of timber harvesting. The Polish reality is dominated by small, one- or two-person forest enterprises with insufficient capital. Certification of forest enterprises has been conducted in recent years with the support of the State Forests' administration (Kapral, 2000).

One of the crucial aspects of assessment is the method of performing forest utilization tasks in accordance with proper regulations, conforming to the obtaining legal standards. An issue underestimated but very important in many aspects is the knowledge of appropriate standards of the time of economic task performance. This knowledge, useful both for foresters and for forest enterprise owners, allows for the proper construction of tender procedures and for the planning of commission performance.

The amended Catalogues of Forest Work Time Standards, which have been in force in the State Forests units since 2003, are also useful for forest enterpreneurs. The tabular data in these standards present the average working conditions in selected field conditions and include the specifications of tasks connected with particular technological systems and particular timber harvesting technologies.

Most studies treat the issue of the modelling of time consumption (productivity) at work-stands or within whole harvesting technologies as a relation between the volume of the harvested timber and a selected category of effective working time, which increases the precision of inference. The conscious simplification consists in separating the influence of particular factors on the assessed variable and a lack of possibility to assess their joint effect. However, it is only the multi-criterion consideration of the analysed relations that shows the real picture of the phenomenon.

The objectivism of assessment of a given technology is connected with the measurement the time of the observed operations. The more widely the time of obtaining a product (effective time, operational time, shift time) will be considered, the more complete the assessment of the operations will be. The present research assumes that the operational time is the sufficient level of generalization. In each case, it is crucial to extract from the general structure of a shift those categories of time which significantly affect the level of time consumption. This is the way to indicate the activities which should be focused on at the stage of shift optimalization. The above-mentioned interdependence of the particular categories of time, reflecting both the specific features of a given technology and the characteristic identifiers of a stand, should be expressed as different percentages.

The introduction of worktime standards has always attracted much interest (Cserjes, 1989; Lukačka, 1989; Döhrer, 1998; Grzegorz, 2003; Derek, 2004; Kusiak, 2006). Standardization, often understood only as an element of control, is nevertheless also a tool used to plan the performance of economic tasks properly. For this reason, the use of time consumption catalogues by the State Forests encourages critical assessment of the standards adopted in them.

2. Research aim and scope

Due to the changing technical capacities of timber harvesting and considering the necessity to update the quantification of the multicriterial influence of selected factors on the level of time consumption, an attempt was made at preliminary assessment of this phenomenon. Constructing a model of time consumption for different timber harvesting technologies would allow for making the time standards of job performance realistic and for undertaking research on such standardization that would be useful both for the State Forests as the employer and for forest enterprises as contractors.

The aim pf the present study was to determine the models of characteristics of time consumption of skidding by means of Fransgård winch aggregated with the farm tractor (referred to as *WINCH* below). The modelling consisted in approximating the mathematical functions which describe the following relation:

$$EST_{WINCH} = f(stand\ structure,\ task\ intensity,\ elements\ of\ working\ day\ structure)$$

where:
EST_{WINCH} – the synthetic index of Empirical Technological Efficiency at the work stand: *WINCH*

The present research on hauled skidding with the use of cable winches aggregated with farm tractors, commonly used in Polish forestry, shows the current technical capabilities of timber harvesting as performed by small forest enterprises with often insufficient capital. The farm tractor is the most common equipment used for work in agriculture (in the broad sense of the term), and therefore also in forestry (Gil, 2007). In Poland, about 65% of skidding operations are performed with the use of tractors.

The present research was conducted in pine, beech, fir and spruce stands. The scope of the operations, limited to the stands of early and late thinning, made it possible to optimize the time consumption model in a group of stands which had the highest share of area and volume. It is in these stands that the performance of timber harvesting tasks is particularly difficult, especially as concerns the part of skidding operations from the stem to the skidding trail. This is affected by the spatial structure of such stands as well as by the volume and dimensions of logs. It is in stands of middle age classes that the largest

problems occur with the determination of proper levels of the time standards, used in the procedures of tenders for job performance in the State Forests.

3. Methods

The research plots under the present resarch were situated within the Regional Directorate of the State Forests in Cracow, the Regional Directorate of the State Forests in Katowice and the Forest Experimental Station in Krynica (Tab. 1).

Table 1. Characteristics of stands on sample plots

Forest Inspectorate	Thinning	Forest district	Compartment	Forest area [ha]	Forest site type	Species	Age [years]	Stocking of stand	Crown density	D.B.H. [cm]	Height [m]	Stand quality	Large timber– [m³/ha]
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Dąbrowa Tarno-wska	Early	Wał Ruda	68d	5,19	Fresh Mixed broadleaved forest	Pine	25	0,9	Full crown closure	13	12	Ia	140
	Late	Wał Ruda	58d	4,96	Moist mixed coniferous forest	Pine	45	0,7	Moderate crown closure	22	20	Ia	200
Gorlice	Early	Dominikowice	48a	30,46	Mountain forest	Fire	47	1,0	Full crown closure	18	17	I	202
	Early	Dominikowice	45b	26,01	Mountain forest	Fire	47	1,1	Moderate crown closure	18	17	I	73
	Late	Małastów	316g	5,62	Mountain forest	Fire	97		Broken crown closure	45	21	III	146
	Late	Małastów	300c	8,07	Mountain forest	Fire	97	0,6	Broken crown closure	36	24	III	239
Sucha	Early	Juszczyn	333b	6,37	Mixed mountain forest	Beech	47	1,1	Moderate crown closure	15	19	I	182
LZD	Late	Tylicz	152a	6,49	Mountain forest	Beech	70	1,1	Moderate crown closure	30	26	I	444
Nowy Targ	Early	Stańcowa	245c	9,19	Mixed mountain forest	Spru-ce	25	1,0	Full crown closure	7	8	I.5	10
	Late	Stańcowa	250d	1,74	Mixed mountain forest	Spru-ce	60	1,2	Moderate crown closure	24	23	I	503

In the areas chosen for their full density and uniformity of forest taxation features (breast-height diameter, height) and for their species composition, experimental plots of 0.5 ha and dimensions 50 x 100 m each were set up so that the longer side of each plot was adjacent to the skidding trail. On each plot, at 32 circular plots of 50 m² each, complete stock-taking was done of all trees thicker than 7 cm.

The equipment used in the present research was Fransgård V6000GS winch aggregated with Pronar 5112 farm tractor. The timber was harvested in the tree length system (TLS) (Laurow, 2000). Hauled cable skidding was performed in the direction towards the skidding trail at the maximum distance of 50 m. No additional equipment, such as skidding tongs or skidding sledge, was used to facilitate skidding and each item was attached to the collective rope by means of standard attachment ropes with slide locks. One collective rope served for the skidding of maximum 6 logs. The winch operator operated the skidding from the skidding trail. The basic technical data of Fransgård V6000GS winch (Figures 18-21) aggregated with Pronar 5112 farm tractor are presented in Table 2.

Table 2. Technical data of Fransgård V6000GS winch aggregated with Pronar 5112 farm tractor

	Fransgård V6000GS	
1.	Wymiary lemiesza: height. / width.	860 / 1700 mm

2.	Weight	550 kg
3.	Pulling power	6 t
4.	Power consumption	50-90 KM
5.	Rope diameter	11 mm
6.	Rope length	50-120 m
7.	Winding speed (at 540 revolutions/min.)	0,5-1,3 m/s
8.	Height (without safety shield)	1660 mm
9.	Total height	2400 mm
	Pronar 5112	
10.	Dimensions: length / width / height	4130/1960/2560 mm
11.	Front/rear wheel track	1570-1730/1500-1800
12.	Weight	4040 kg
13.	Engine, power of engine	diesel, 60 kW/ 2300 revolutions/min

A constant time study of theoperations was conducted with the working day picture method during the skidding tasks (Monkielewicz and Czereyski, 1971; Sajkiewicz, 1981). Time was measured with the use of PSION Workabout computer with specialist „Timing' software for conducting time studies (Sowa and Szewczyk, 2005). The registered duration of particular operations was assigned to given categories according to BN-76/9195-01 in the National Forest Equipment System (Botwin, 1993). The outline of the classification of the operational worktime and the adopted symbols are presented in Table 3.

Table 3. Worktime classification

T_{02} – Operational worktime	T_1	Effective worktime	T_{13}	Time of skidding
	T_2	Auxiliary time	T_{21}	Time of waiting for help in task execution or for the end of other activities
			T_{22}	Time of walking in workplace
			T_{23}	Time of load attachment and detachment
			T_{24}	Time of unlocking of skidded piece of timber

On completion of the field work, the volume of the obtained timber was calculated, stock-taking was performed of the trees remaining on the circular plots and the intensity of planned thinning was determined (1), (2).

$$W_{iip} = \frac{I}{L} * 100\% \quad (1)$$

$$W_{sip} = \frac{W_{iip}}{W_{mip}} \quad (2)$$

where *I, L, W_{iip}, W_{mip},* are the number of trees before the felling on the circular plots, the number of trees removed from the circular plots, the index of quantitative harvesting intensity, the index of harvesting intensity in terms of volume (W_{mip} = timber volume removed from the circular plots / timber volume before the felling on the circular plots *100%)

In order to obtain more stable results, time consumption was calculated by relating the obtained timber volume to the operational time T_{02} (Giefing and Gackowski, 2001).

Due to the accordance of the time consumption, calculated for particular sections, with the normal distribution as well as due to a lack of uniformity of variance, analysis of differences of the mean values of time consumption was conducted using the parametric t-Student test. Examination of the dependence of the time consumption observed at work stands on stand characteristics, felling intensity indexes, timber characteristics and factors of the working day structure was conducted using multiple regression procedures. The significance of null hypotheses H_0 was determined for the level of significance α=0,05. Statistical calculations were done using STATISTICA 6 PL programme.

4. Results

Research included 24 plots, 3 in each selected stand for each thinning category. Felling intensity was determined at 768 measurement points (circular research plots), where stock-taking of 4,360 trees was performed. The harvesting resulted in the removal from the circular plots of 620 trees, which constituted about 14% of their number and 145 m^3, i.e. over 9% of the volume of trees recorded before the operation.

Figure 1 presents the mean values of the index of the total harvesting intensity w_{sip}, calculated for the analysed conditions.
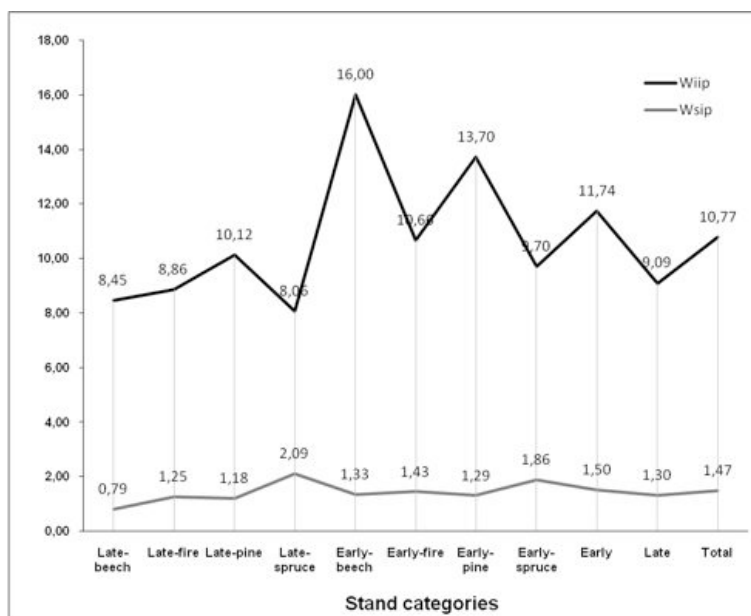

Figure 1. The indexes of quantitative harvesting intensity W_{iip} and the total harvesting intensity W_{sip} in the analysed stands

The W_{iip} index reached higher values in the early thinning stands. Its level ranged from 9.7 to 16. In all cases, the percentage of the number of removed trees was always higher than the volume removed. The analysed index reached the highest values in early thinning in beech and pine stands. The highest value W_{sip}, i.e. 2.09, was noted in spruce stands in late thinning whereas the lowest one, amounting to 0.79, was observed for the late thinning in beech stands. The mean W_{sip} values were by almost 20% higher in early thinning stands. The highest values were noted in spruce stands ($W_{sip} = 2.09$ in late thinnings and $W_{sip} = 1.86$ in early thinnings), where in both usage categories the W_{sip} was much higher than in the other cases. The W_{sip} index, when calculated individually for each research plot, was then included in the equations of regression describing the time consumption of timber harvesting (*EST*).

In the course of the harvesting and skidding work, a time study was conducted for the operations performed during work on the research plots. The measurement base of the duration of the distinguished job categories included 7,034 cases whose total time exceeded 70 hours. Part of the measured shift time (the time category) was included in the equations describing the time consumption of timber harvesting (*EST*). The coefficient of the use of the operational shift time was on the level of approximately 0.75, which points to considerable reliability of the equipment used and to good work organization.

Figure 2 presents the percentages of operations noted in the operational time at the examined work-stand.
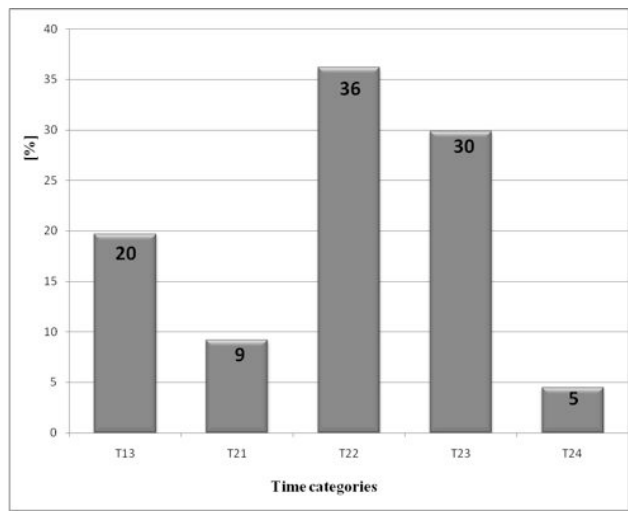
Figure 2. The structure of operational worktime for skidding performed with the farm tractor

The examined skidding operations were characterized by very high (36%) share of the time of walking in the workplace (T_{22}). When walking, the winch operator extended the collective rope and fastened a few skidded logs with attachment ropes (between 4 and 6 at a time), which imposed long walking times. The skidding operation itself was not time-consuming (T_{13} amounted to20%) but the auxiliary operations of attaching and detaching logs increased the time consumption considerably (30%).

Figure 3 presents the time consumption calculated for the analysed work-stand. Results of the analysis of the differentiation of the mean time consumption values in subsequent sections are presented in Table 4.
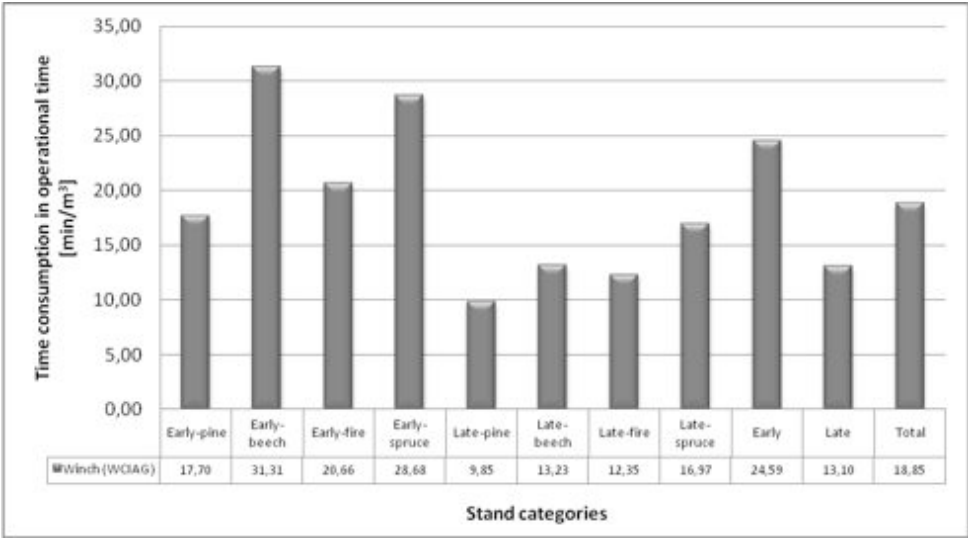

Figure 3. Time consumption in operational time

Table 4. Significance of differences between the mean time consumption values in the operational time for skidding with the use of the farm tractor

Compared variants		Winch										Compared variants	
		Early				Thinning		Late					
		Species						Species					
		Pine	Beech	Fir	Spruce	Early	Late	Pine	Beech	Fir	Spruce		
Species	Pine		t=-2,47 p=0,02	t=-2,08 p=0,04	t=-1,44 p=0,16	t=-4,51 p=0,00			t=-1,84 p=0,07	t=-1,60 p=0,12	t=-3,77 p=0,00	Pine	Species
	Beech			t=1,89 p=0,10	t=0,28 p=0,78					t=0,38 p=0,70	t=-1,48 p=0,15	Beech	
	Fir				t=-1,04 p=0,31						t=1,98 p=0,06	Fir	
	Spruce											Spruce	

Skidding operations were performed with the mean time consumption of 18.45 min/m^3, which was a value close to the time consumption noted in the skidding technology using winches aggregated with chain saws (Szewczyk, 2009). Statistically significant differences were noted between the levels of time consumption in the early-thinning stands (24.59 min/m^3) and the late-thinning stands (13.10 min/m^3) (Fig. 3). The lowest time consumption was noted in late-thinning pine stands (9.85 min/m^3) and the highest in early-thinning beech stands (31.31 min/m^3). There were no groups of stands which would differ significantly as concerns their time consumption level.

The time consumption level is one of the factors which allow for determination of the usefulness of a given technology to perform particular forest management tasks. For this reason, the term time consumption will be replaced below by another, proposed by the present authors, namely *ETS* – the synthetic index of *Empirical Technological Efficiency* (Szewczyk, 2007). The parameters of the equations (2-4) allowing for the approximation of the *EST* level were estimated for factors related to the features of the stand, skidded timber and elements of the working day structure. Table 4 also presents the values: R, R^2, Std mistake, test values and the probability level p.

Table 4. Parameters of the equations of regression of the *EST* index

Nr	*EST*	Equation - exactitude of adjustment					Independent variables					
		R	R$^2_{pop}$	F	p	Mistake ±	Variable	B	Beta β	Mistake std.	t	p
1	2	3	4	5	6	7	8	9	10	11	12	13
2	Early thinning	0,66	0,41	21,98	0,00	14,36	*Constant*	50,34	-	6,61	7,61	0,00
							T$_{22}$ [%]	-129,1	-0,64	20,30	-6,36	0,00
							w$_{szt}$	0.04	0,25	0,02	2,55	0,01
3	Late thinning	0,78	0,59	29,35	0,00	3,93	*Constant*	11,84	-	2,09	5,65	0,00
							T$_{13}$ [%]	27,43	0,30	7,72	3,55	0,00
							T$_{22}$ [%]	-27,27	-0,47	4,98	-5,48	0,00
							w$_{sip}$	2,39	0,41	0,51	4,71	0,00
4	Total	0,64	0,39	26,69	0,00	11,73	*Constant*	30,85	-	3,36	9,18	0,00
							0=Late thinning 1=Early thinning	6,62	0,22	2,84	2,33	0,02
							T$_{22}$ [%]	-75,43	-0,49	10,90	-6,91	0,00
							w$_{szt}$	0,03	0,26	0,01	2,71	0,01

The strongest relations between the *EST* level at the work-stand of the WINCH OPERATOR in mature stands were found for the following variables: walking time T_{22} (β=-0.49) and w_{szt} (β=0.26). The estimated time consumption in early-thinning stands should be by about 6 min/m^3 higher in comparison with late-thinning stands. An increased share of walking time T_{22} in a shift results in a decrease in time consumption (parameter -75.43), which at first sight seems incorrect as the T_{22} time is the auxiliary time

rather than the effective time. However, it must be noted that at the analysed work-stand this time is connected with walking in order to attach to the collective rope several logs which are then skidded together as a bunch. Thus its higher share results in higher volume of one load of skidded timber, which lowers the time consumption level. This phenomenon was better visible in the case of assessing the *EST* in early-thinning stands (β_{T22}=-0,64), which is understandable considering lower volume of a single log. This would point to the need to carry out skidding of whole bunches of logs on a collective rope in stands of younger age classes.

The analysed spatial relation (multiple independent variables) is presented in this study as a relation which is a polynomial of the first degree of multiple variables. For the purpose of assessing the time consumption for jobs in forestry, the linear regression model is the most frequently used by researchers (Häberle, 1990; Samset, 1990; Lukáč et al., 2000; Bibliuk, 2004; Messingerová, 2005; Sowa et al., 2009; Sowa and Szewczyk, 2008). The total time consumption of timber harvesting technologies, taking into consideration the various jobs involved, may be assessed by totalling appropriate multiple regression equations calculated for particular jobs (Zečić and Marenče, 2005). This may constitute the method of predicting the time consumption level for different technological variants (logical from the point of view of work organization).

In the present study, the *EST* index was expressed as several linear functions of multiple variables. Each time, there are two groups of variables which generally characterize a stand and the character of stand management tasks (the first group) as well as the percentages of the selected elements of the working day structure in the operational time, describing the basic characteristics of timber harvesting technologies (the second group). Their changes are due to differentiation of stand features and, because the examined times are generally the skidding times, they complement the variables included in the first group. Such a total approach is an innovative solution, proposed by the present authors.

5. Conclusions

1. The average time consumption of skidding by means of the cable winch aggregated with the farm tractor in the operational time, assessed in the examined mature stands, amounted to approximately 18 min/m^3. Significant differences were noted in the time consumption levels between early thinning (about 24 min/m^3) and late thinning (13 min/m^3).
2. The structure of the operational time of skidding by means of the cable winch in mature stands was characterized by a large share of auxiliary times T_2: 80%, as many as 36% of which was the walking time T_{22} while 30% was the time of load attaching and detaching T_{23}.
3. An equation of multiple regression was elaborated for the purpose of describing the changes in the time consumption level of skidding, namely the *Empirical Technological Efficiency* index (*EST*). The *EST* depends on environmental factors (stand, felling category), elements of the working day structure (the share of an appropriate time category in a shift), characteristics of the harvested timber (volume) and operation intensity (the w_{iip} indexes of quantitative harvesting intensity and the w_{sip} index of total harvesting intensity). The strongest relations between the *EST* and the analysed variables occurred for factors connected with the percentage of walking time T_{22}.
4. High time consumption of the examined skidding technology and a large share of the time of waiting for help indicate difficult work conditions in stands of middle age classes, consisting in frequent blocking of skidded logs and problems connected with controlling the skidding from the skidding trail.
5. The measurements of thinning intensity, used for the approximation of the *EST*, may be determined prior to forest management operations using the data contained in Forest Management Regulations and in Standing Timber Assessment. It allows for the rational design of the most effective technological solutions. This makes it possible to apply the results directly in given field conditions of timber harvesting.

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