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MULTIFACTOR ANALYSIS OF TIME CONSUMPTION IN MANIPULATION AND CUTTING STACKED WOOD INTO LENGTH

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Abstract. Cutting stacked wood into length by means of a petrol chainsaw is a typical technical and technological wood harvesting solution. Due to the fact that wood harvesting is most commonly performed with the use of Tree-Length-System (TLS) or Long-Length-System (LLS), cutting into length in Poland is performed either after the first stage of skidding stems or logs to the skidding route or after the second stage of transportation, that is at the depot. Research was carried out in depots, during early and late thinnings of pine, fir, spruce and beech stands by means of manipulation and cutting into lengths using petrol chainsaws (Table 1). The aim of the study was to specify time consumption on the basis of the relativeness of EST = f (category of harvesting, roller's length, chosen elements of the working day structure). Continuous time-motion analysis was carried out, according to the classification presented in Table 2. After completing harvesting, the produced material was received. Figure 1 presents the percentage of work activities observed in operational time. Performing cutting into length activities at a discussed working site resulted in high time percentage in case of T_{12} and T_{22} times. Table 3 presents the average values of time consumption correlated in terms of soft and hard wood species in the categories of early and late thinning stands. Some statistically significant differences in labour consumption levels have been demonstrated in case of specific stands and harvesting technologies. One multiple regression equation has been estimated – for early and late thinning. The regression model has been expressed by a formula (1). The equation parameters have been compiled in Table 4. Research results point to the relation between time consumption, the specific elements of the time structure of a working day, and the length of produced rollers expressing variable volume of produced rollers.

Key words: wood harvesting technology, manipulation, cutting into length, time consumption

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INTRODUCTION AND THE AIM OF THE STUDY

Wood manipulation and cutting into length in order to obtain certain wood assortments constitutes an element of the wood harvesting process which is normally carried out in Poland by means of petrol chainsaws. The percentage of cutting into length time within operative time of the working shift is normally considered a derivative of the processed timber volume. The proportion of cutting into length time in pine forest stands varies between 49% and 46% of the operational time and decreases with tree diameter increase [Bojarewicz 1981]. The reason why Kubiak [1978] determined the percentage of manipulation within the total wood processing time at the level of ca 40% (while, at the same time, he also observed its increase in case of lower diameter classes, like in case of data quoted above), was probably the variability of stands and, perhaps, different expectations of wood recipient as well. The above mentioned element of raw material quality which has to be taken into account during manipulation, was undoubtedly reflected in much lower cross-cutting time percentage of the fir forest stands, which, according to Porter and Strawa [2006], was ca 11%. The percentage of manipulation and cutting into length timber of smaller dimension during late thinnings, and especially during early thinnings, should be substantially higher in comparison to the above presented data. For instance, Kubiak [1980] estimated it to be at the level of over 73% for beech early thinnings. A certain simplification of the suggested methods of estimating time consumption of manipulation consists in separating the influence of individual factors on the estimated variable and no possibility of assessing these factors' joint influence. The real image of the phenomenon can be observed during multi-criterion analysis. The exact assessment in timber harvesting is difficult due to high variability of the working environment criteria, and the choice of the right criteria influencing the level of time consumption becomes a priority.

The aim of the research was determining the model of time consumption characteristics for a petrol chainsaw operators' position during manipulation and cutting to length. The issue has been considered based on the dependence of the form of:

EST = f (category of harvesting, roller's length, chosen elements
of the working day structure)

where EST is a synthetic coefficient of the Empirical Technological Efficiency (level of time consumption approximated by multiple linear regression).

The study was conducted in depots during early and late thinnings of pine, fir, spruce and beech stands.

METHODOLOGY

The studies were conducted in stands from the 1st to the 3rd age class within the area of Forest Inspectorates: Sucha, Dąbrowa Tarnowska, Gorlice, Nowy Targ and in the stands of the Forest Experimental Plant in Krynica (Table 1).

The skidding of the raw material was performed at the depots located in the vicinity of the stands and collected at the manipulation yard in form of irregular stacks of long-length timber, at maximum height of 1.3 m, in the same form as skidding of long-length timber by hauling proceeded. During the manipulation and cutting into length, the con-

Table 1. Selected valuation featured of the stands studied
Tabela 1. Wybrane cechy taksacyjne badanych drzewostanów

Forest inspectorate Nadleśnictwo	Thinning category Kategoria trzebieży	Forest unit Leśnictwo	Compartment Oddział	Species Gatunek	Age, years Wiek, lata	Index of stocking Zadrzewienie	Diameter at breast height, cm Pierśnica, cm	Height, m Wysokość, m	Timber quality class Bonitacja
Dąbrowa Tarnowska	ET TW	Wał Ruda	68d	pine – So	25	0.9	13	12	Ia
	LT TP	Wał Ruda	58d	pine – So	45	0.7	22	20	Ia
Gorlice	ET TW	Dominikowice	48a	fir – Jd	47	1.0	18	17	I
	ET TW	Dominikowice	45b	fir – Jd	47	1.1	18	17	I
	LT TP	Małastów	316g	fir – Jd	97	1.0	45	21	II
	LT TP	Małastów	300c	fir – Jd	97	0.6	36	24	II
Sucha	ET TW	Juszczyn	333b	beech – Bk	47	1.1	15	19	I
LZD	LT TP	Tylicz	152a	beech – Bk	70	1.1	30	26	I
Nowy Targ	ET TW	Stańcowa	245c	spruce – Św	25	1.0	7	8	I.5
	LT TP	Stańcowa	250d	spruce – Św	60	1.2	24	23	I

ET TW – early thinning, LT TP – late thinning.
ET TW – trzebież wczesna, LT TP – trzebież późna.

tinuous time-motion analysis of the activities observed was carried out [Grzywiński et al. 2007, Giefing et al. 2012]. Time measurement was noted with the use of the PSION Workabout microcomputers, with "Timing" software for the time-motion analysis [Szewczyk 2010]. The duration of particular activities registered during the studies was classified to specific categories adopted as BN-76/9195-01 in the National System of Forest Machines [Botwin 1993]. After the above works have been completed, the middle diameters of one hundred pieces of processed rollers, randomly selected in thickness classes, were measured. Volume of timber processed on the particular study plot was calculated as the product of volume of an average roller and number of cutting into length operations during the time-motion analysis. The time consumption was calculated referring the acquired timber volume to the operational time [Giefing and Gackowski 2001]. The diagram of operational time classification is presented in Table 2.

The study on significance of differences in average values of labour consumption of manipulation in the distinguished stands was performed on the basis of parametric t-Student test. Studies on dependence of timber manipulation time consumption on the stand category, length of the processed assortments and on the working day structure factors were carried out applying the procedures of multiple regression.

Table 2. Classification of distinguished operational time categories
Tabela 2. Klasyfikacja wyróżnionych kategorii czasu operacyjnego

T_{02} Operational working time – Operacyjny czas pracy		
T_2		T_1
auxiliary time – czas pomocniczy		effective time – czas efektywny
T_{22}	T_{21}	T_{12}
time of transfers at the workplace czas przejść w miejscu pracy	waiting time for assistance in performing the activities or at the end of other activities czas oczekiwania na pomoc w wykonaniu lub na koniec innych czynności	time of cross cutting into length czas przerzynki

RESULTS AND DISCUSSION

During the studies, in total, volume of 600 rollers of lengths: 1 m, 1.1 m and 1.25 m was measured. The measurement base of working time periods registered at the workplace under analysis covered 4580 activities during the operational working time, which resulted in the total of 26886 sec. of measurements (448 min).

Figure 1 presents the percentage of working activities observed in operational time. At the workplace under analysis, very high, 60-per cent share of transfer time at the workplace was characteristic. During this activity, the chainsaw operator had to measure the assortment manipulated with the measuring tape and this is probably why this time category made such a significant percentage of the general operational time.

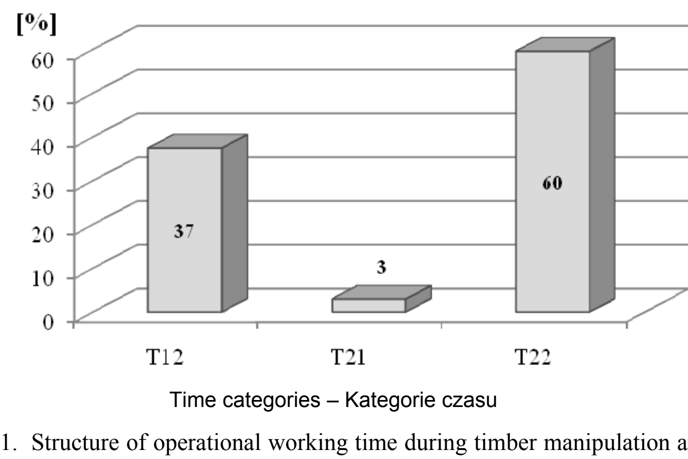

Fig. 1. Structure of operational working time during timber manipulation and cross cutting
Rys. 1. Struktura operacyjnego czasu pracy przy wykonywaniu manipulacji i przerzynki drewna

The very short time of cutting into length in case of a single piece was probably not a property distinguishing the studied types of stands, therefore, the labour consumption could have also been influenced by the transfers between the forefronts of timber pieces. The 3-per cent share of technological downtime T_{21} resulted from the adopted work organisation in which the assistant moved the rollers after manipulation aside. However, the working pace of the chainsaw operator was higher, as compared to the assistant, which has caused the necessity to adjust the "works" of the chainsaw operator and the assistant.

Assuming the relevant and constant power of chainsaw feed in the kerf [Kozłowski 2002], it was assumed with certain approximation that significant differences in labour consumption of timber cutting into length occur between the species of soft and hard timber [Górski 2001, Kozłowski 2003]. For the above reasons, within the category of early and late thinning, pine, fir and spruce were classified as one group while beech was classified as the second group. This responds, to certain extent, to the classification of working time standards applicable in PGL LP [Zarządzenie... 2003]. In Table 3 results of analyses of the average values and variability of time consumption, obtained for soft (So – pine, Jd – fir, Św – spruce) and hard (Bk – beech) wood species in the categories of early and late thinning stands are summarised.

Table 3. Time consumption of timber manipulation and cross cutting in the operational working time
Tabela 3. Czasochłonność manipulacji i przerzynki drewna w operacyjnym czasie pracy

Thinning – Trzebieże P_0 = 13.66, σ = 4.68			
early thinning – trzebieże wczesne P_0 = 17.76, σ = 3.82		late thinning – trzebieże późne P_0 = 10.08, σ = 0.73	
Pine – So, fir – Jd, spruce – Św P_0 = 20.17, σ = 2.16	beech – Bk P_0 = 13.41, σ = 1.86	pine – So, fir – Jd, spruce – Św P_0 = 10.29, σ = 0.66	beech – Bk P_0 = 9.44, σ = 0.65

P_0 – time consumption, min/m^3, σ – standard deviation.
P_0 – czasochłonność, min/m^3, σ – odchylenie standardowe.

The average labour consumption at the workplace under discussion reached 13.66 min/m^3 for all the variants under analysis. The differences in labour consumption observed in thinning categories reached about 7 minutes, which made about 40% of the labour consumption obtained for TW. This result should be associated with increased volume of single manipulated rollers of thicker raw material coming from late thinning. The average volumes of one roller of timber coming from early and late thinning stands reached, respectively, 0.013 m^3 and 0.031 m^3. The observed differences in the range of about 138% correspond to the tendency described. The visible smaller difference for labour consumption results from lower efficiency of cutting for larger aggregate cross-section surface [Grodecki and Stempski 1997].

In the early thinning category, considerably higher labour consumption was observed in the group of soft wood stands (So+Jd+Św) – it has reached 20.17 min/m^3 and it was worse by about 66% as compared to the hard wood stands (Bk). In the late thinning category, the differences observed were not so clear and although statistically significant, the time consumption levels in soft and hard wood stands differed only by about 9%. The results presented are contradictory to the data published by Górski [2001] or Kozłowski [2003], who demonstrated lower level of labour consumption for cutting into length in case of soft wood timber species. Such a picture could have been affected by different condition of bluntness of chainsaws used for cutting of pine and beech into length. As Grodecki and Stempski [1997] have demonstrated, the decrease of cutting efficiency for sand-covered timber using, e.g. the Oregon 21BP chainsaw, as compared to cutting of clean timber, amounts to almost 30 cm^2/s, i.e. about 50%. Thick and coarse outer bark of pine during the skidding by hauling became contaminated much more than in case of beech. Additional factor which might have influenced the circumstances described was large number of cutting into length operations performed for thin timber. The situation presented refers to thicker timber of late thinning to a slightly lesser extent, accordingly, following the described way of reasoning, the result obtained for such stands can be justified.

In majority of the studies, the timber manipulation time was correlated to thickness of trees. In beech thinning stands, Kubiak [1980] approximated the linear regression function which determined the proportional increase of cutting into length time with the increasing diameter at breast height. Similar results of such analysis were obtained for pine forest stands, in which Kubiak [1978] and Bojarewicz [1981] determined analogical relationships, at high precision (R = 0.97 and R = 0.72). According to Rebula [2002], the dependence of manipulation time in deciduous thinning stands on the length and volume of the top tree part, from which the stack assortments are produced, is of curvilinear, hyperbolic nature. Such relationship between the diameter at breast height of the processed trees and their manipulation time was also found by Nikolić and Bajić [1991]. According to them, the above-mentioned correlation should be applicable both to beech stands and spruce stands.

While analysing the spatial relationships (many independent variables), the dependence under the form of the polynomial of the first degree of many variables is the simplest and the most commonly considered correlation. The theory of adjustment of the polynomial coefficients was precisely elaborated, and the polynomial function itself is easy for interpretation. Under the conditions of labour consumption estimation at workplaces in forestry, the linear regression is the model most commonly used by researchers [Häberle 1992, Samset 1990, Messingerová 2005, Sowa et al. 2009, Szewczyk 2011]. The aggregate labour consumption of timber harvesting technology, taking into consideration various workplaces, may be estimated by summing up the respective multiple linear regression equations. Such procedure can be also found in other studies of similar type [Zečić and Marenče 2005]. The above concept allows for flexible construction of approximated time consumption in different technological variants. Therefore, in this study, it has been decided to apply the multiple linear regression.

For the workplace under analysis, one regression equation was developed, taking into consideration the utilisation category, selected time categories and the length of the assortments processed (1) (Table 4). In that way, in the set of independent variables, the volume of the processed raw material was considered, arising from various dimensions of timber harvested in the stands of different age classes and different roller sizes, as well as the characteristic features of the studied working technology, including the manual measurement of the assortment length and difficulties at work caused by the necessity to move the rollers aside after the cutting into length has been performed.

$$EST_{MANIP} = 34.81 + 3.92 \cdot x_1 - 61.71 \cdot x_2 - 27.09 \cdot x_3 + 16.25 \cdot x_4 \pm 5.53 \quad (1)$$

where:

EST_{MANIP} – foreseen value of EST indicator, min/m^3,
x_1 – zero-one variable of stand category reaching 1 for early thinnings and zero for late thinnings,
x_2 – percentage share of T_{12} time category,
x_3 – percentage share of T_{22} time category,
x_4 – length of the assortments processed, m.

The high value of the determination coefficient R^2 (0.82) demonstrates the very good adjustment of the studied regression function to the empirical data.

The nomogram EST at the workplace studied, for early and late thinning stands is presented in Figure 2.

For the assumed values of share of cutting into length time (37%) and transfer time (60%), EST in the late thinning stands is lower. The proportional increase of labour consumption with the change in length of the assortments processed is noticeable, which could be associated with longer transfer time between the successive sites of cutting into length. In the equation estimated in such a way, the strongest correlations were found for the share of cutting into length time for which the value of standardised equation parameter β reached –0.79. The minus sign demonstrates the tendency of decreasing labour consumption in late thinning stands, in which trees of higher volume are harvested. Similarly, close correlations occurred in case of the variable: thinning category (β = 0.58).

Table 4. Regression analysis
Tabela 4. Analiza regresji

$R = 0.91$, $R^2_{popr} = 0.82$, $F = 73.83$, $p = 0.00$				
	standardised equation parameter standaryzowany parameter równania β	standard error błąd standardowy B	t	P
Absolute term Wyraz wolny	–	34.81	4.53	0.00
x_1	0.58	–14.92	–3.95	0.00
x_2	–0.79	–61.71	–3.97	0.00
x_3	–0.31	–27.09	–3.07	0.00
x_4	0.67	16.25	5.15	0.00

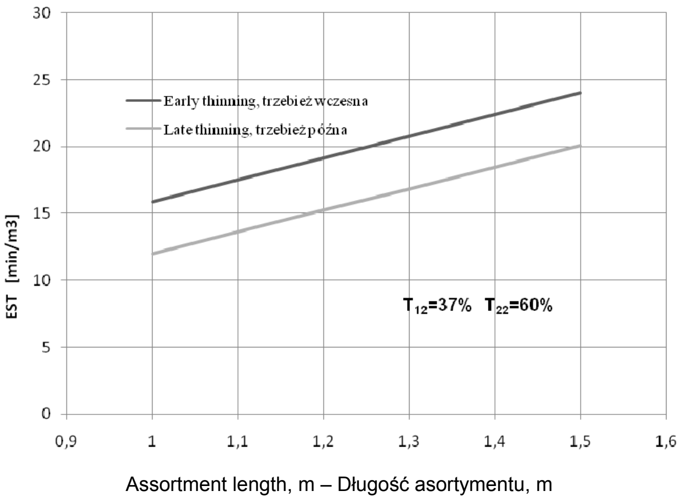

Fig. 2. Nomogram of EST indicator for manipulation and cutting of stacked wood into length
Rys. 2. Nomogram wskaźnika EST manipulacji i wyrzynki drewna stosowego

FINDINGS AND CONCLUSIONS

The average time consumption of manipulation and cutting into length for rollers in the operational time has oscillated at the level of about 13.2 min/m^3, whereas it was significantly lower in late thinnings, as compared to early thinnings, reaching 10.08 min/m^3 and 17.76 min/m^3, respectively.

The time consumption of timber manipulation was considered jointly for soft wood species (pine, fir, spruce) and hard wood species (beech). Statistically significant differences have been observed in time consumption levels of distinguished stand groups and for utilisation categories.

The time consumption level was associated with the shares of the most significant working time categories in the operation discussed, such as time of cutting into length and transfer time, as well as with the length of the assortments processed.

The mathematical equation of EST indicator, estimated in the study, determining the time consumption level at manipulation in thinning stands, may constitute an auxiliary element while planning the performance of the economic tasks in the area of timber harvesting.

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WIELOCZYNNIKOWA ANALIZA CZASOCHŁONNOŚCI MANIPULACJI I WYRZYNKI DREWNA STOSOWEGO

Streszczenie. Operacja przerzynki drewna stosowego wykonywana z użyciem pilarki spalinowej jest typowym rozwiązaniem techniczno-technologicznym pozyskiwania drewna. Wobec dominującego w naszych warunkach pozyskiwania drewna w systemie drewna długiego (TLS) lub dłużycowego (LLS), jest wykonywana po pierwszym etapie zrywki dłużyc czy kłód do szlaku zrywkowego lub po drugim etapie transportu, na składnicy. Badania przeprowadzono na składnicach przyzrębowych w sosnowych, jodłowych, świerkowych oraz bukowych drzewostanach trzebieży wczesnych i późnych, w których prowadzono manipulację i wyrzynkę surowca z zastosowaniem pilarek spalinowych (tab. 1). Celem pracy było określenie czasochłonności na podstawie zależności postaci EST = f (kategoria użytkowania, długość wałka, wybrane elementy struktury dnia roboczego). Podczas wykonywania prac prowadzono chronometraż ciągły czynności według klasyfikacji przedstawionej w tabeli 2. Po zakończeniu pozyskania odebrano wyrobiony surowiec. Na rysunku 1 przedstawiono udziały procentowe czynności roboczych zaobserwowanych w czasie operacyjnym. Wykonywanie na omawianym stanowisku pracy czynności związanych z przerzynką scharakteryzowały duże udziały czasów T_{12} oraz T_{22}. W tabeli 3 przedstawiono średnie wartości czasochłonności zestawione w układzie gatunków o drewnie miękkim i twardym w kategoriach drzewostanów trzebieży wczesnych i późnych. Wykazano istnienie istotnych statystycznie różnic w poziomach pracochłonności w wyróżnionych drzewostanach i kategoriach użytkowania. Estymowano jedno równanie regresji wielokrotnej – dla trzebieży wczesnych i późnych. Model regresji przyjął postać opisaną wzorem (1). Parametry równania zestawiono w tabeli 4. Wyniki badań wskazują na występowanie zależności pomiędzy czasochłonnością i określonymi elementami struktury czasowej dnia roboczego oraz długością wyrabianych wałków, oddającą zmienną miąższość wyrabianych wałków.

Słowa kluczowe: technologia pozyskiwania drewna, manipulacja, przerzynka, czasochłonność

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