DOI: 10.2478/frp-2014-0003

Leśne Prace Badawcze (*Forest Research Papers*), March 2014, Vol. 75 (1): 25–30

ORIGINAL RESEARCH ARTICLE

Analysis of the duration of basic logging operations performed using a chainsaw

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Abstract. Motor-manual machinery, i.e. chainsaws, is still commonly used for timber harvesting in Poland, especially in northern-east part of the country. The main goal of this research was to analyse the duration of operations such as felling, delimbing and bucking of the main tree species in Augustów Primeval Forest. Our aim was also to estimate the quantity of fuel necessary to perform these operations as well as the CO_2 emission.

Working's day activity study was selected as a method of time measurement. Data was collected from 8 clear-cuts during the logging of 327 m^3 of timber.

On average, the most time-consuming operation was delimbing (26% of total time). Felling took 15% and bucking 18% of total time. Breaks took up a significant proportion of time (10% of total time), as well as technical maintenance, change of workplace and preparation of work-place that each took up 9%. The average exploitation productivity of lumberjacks reached 7.5 $m^3\ h^{-1}$ and fuel consumption was 0.14 $l\ m^{-3}$.

Results on the duration of operational times confirm earlier research, however due to final felling conditions and large dimensions of trees fuel consumption and emissions of CO_2 were smaller than those given in the existing literature. The most time-consuming operation for coniferous was delimbing (Scots pine 29%, Norway spruce 36% of working time) and for the broadleaves it was bucking (silver birch 27%, black alder 28% of working time). Workers' operational productivity depended on tree species and was the greatest in the case of Scots pine (15.2 $m^3\ h^{-1}$) and the smallest in the case of Norway spruce (6.2 $m^3\ h^{-1}$). Operational productivity was strongly correlated with the volume and the trunk diameter.

Key words: time-consumption, felling, chainsaw, efficiency, Scots pine (*Pinus sylvestris* L.)

1. Introduction

Motor-manual logging, despite increasing the volume of timber harvested by machines, is still basic working technology at clear-cuts. In the scale of the entire country, about 90% of timber is being harvested with the use of chainsaws (Kusiak et al. 2012), although in final felling this amount is smaller. In 2010, about 6.1 mln m^3 of timber was logged (DGLP 2011) within felling areas in State Forests.

Previous studies on productivity and fuel consumption during harvesting with the use of chainsaws concerned mostly western or central parts of Poland (Kusiak et al. 2012; Więsik 1988; Dzialuk 1988), but it is difficult to find any analysis of time consumption in the environmental conditions of Augustowska Primeval Forest. Dominant trees species in Polish part of this primeval forest are: Scots pine (76.20%), Norway spruce (7.35%), black alder (8.80%) and silver birch (5.87%). A significant share of coniferous trees results from the habitat – fresh coniferous

Received 23 July 2013, accepted after revision 26 September 2013.

forest 30.62%, and fresh mixed coniferous forest 38.09% of the area (Sokołowski 2010). This affects the way of management in the stands, the effect of which is common use of clear-cuts. Relatively large trees and their strong branching can significantly limit the use of harvesters.

2. Aim of study

The aim of the study was to analyse time consumption of selected technological operations performed during timber harvesting at the clear-cuts and to determine the average fuel consumption and emissions of carbon dioxide during work at motor-manual technological level in the stands of Augustowska Primeval Forest.

3. Material and methods

Field measurements were conducted in the area of Augustów and Pomorze Forest Districts, at seven strip clear-cuts and one group shelterwood, at sites of fresh mixed coniferous forest, fresh mixed broadleaved forest and ash-alder forest with temperature between –5 and 0°C and a snow cover of about 5 cm.

Observations were conducted using working day activity study. The measurement of the duration for particular operations was performed with the use of electronic timer with an accuracy of 1 second. Fuel consumption was determined based on the number of full fuel tanks during working shift with regard to the fuel left in the tank after the work was finished. Energy expenditure in the form of fuel used to harvest the timber was calculated with the assumption of the fuel energy value equal to 33.75 MJ l^{-1}, and CO_2 emissions were determined including indicators of carbon dioxide emissions (MŚ 2012). Lumberjacks' energy expenditure was calculated based on results of timing and published data (Józefaciuk and Nowacka 1999).

Figure 1 shows the structure of the time adopted for the purpose of the study.

Felling, delimbing and bucking were conducted using professional chainsaws Stihl 361, Stihl 362, Husqvarna 357 XP, Husqvarna 346 XPG and Husqvarna 550 XP. Timber was harvested in short-wood system. After the felling, the whole piece was delimbed and bucked afterwards. Exceptionally, in the case of deciduous species, cross-cutting was done before finishing the delimbing, but the time of particular activities was accurately recorded. During

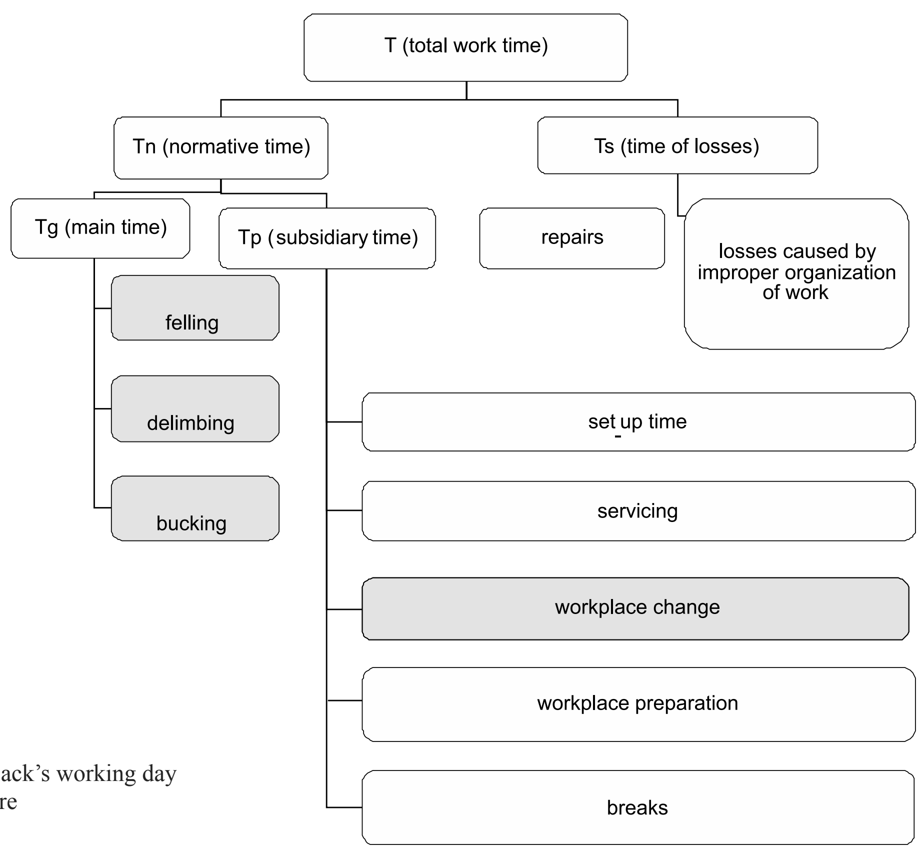

Figure 1. The structure of lumberjack's working day (operations involved in the structure of operational time are in bold)

bucking – for both coniferous and deciduous – log or long timber was made with certain multiples of dimension as well as pulpwood and firewood with a length of 1.2 m.

Felling and delimbing operations were always conducted solely, while there was always at least one more person operating the skidder on the cutting area. Lumberjack did not take part in hooking logs to the skidder nor in stacking up the branches.

The diameter at breast height of each tree was measured before felling. After the felling and delimbing (but before cross-cutting), volume was measured with the use of calipers and tape. Only the following species were felled: Scots pine (*Pinus sylvestris* L.), silver birch (*Betula pendula* Roth.), black alder (*Alnus glutinosa* (L.) Gaertn.) and Norway spruce (*Picea abies* (L.) Karsten) in all classes of thickness and quality.

4. Results

During field measurements, more than 43 hours of observation were recorded. During this time, 200 trees of a total mass of 327.70 m^3 (289.17 m^3 of merchantable timber) were logged.

The delimbing was the most time-consuming operation in the case of coniferous species. On the other hand, in the case of silver birch and black alder, bucking dominated in the time structure. Relatively low share of time losses due to work organisation and repairs was reported (Fig. 2).

The average operational time, including felling, delimbing, bucking and workplace change compared with one tree, ranged from 6.22 min for alder (average mass per tree: 1.63 m^3) to 16.27 min for Norway spruce (average mass per tree: 1.57 m^3), which is shown in Figure 3. Statistical tests performed (Kruskal–Wallis analysis by ranks, α=0.05) showed significant differences in the range of operating time between particular species (p=0.0000).

Based on the data received during field measurements, selected coefficients of working time use were determined based on the methodology suggested by Botwin (1993). The total energy input was a sum of energy of fuel and human energy expenditure (Table 1).

Working time use coefficient is slightly lower than operational time use coefficient as the time of repairs and set-up time were also included in it.

Based on results correlation between some tree attributes and lumberjacks' efficiency or duration of particular

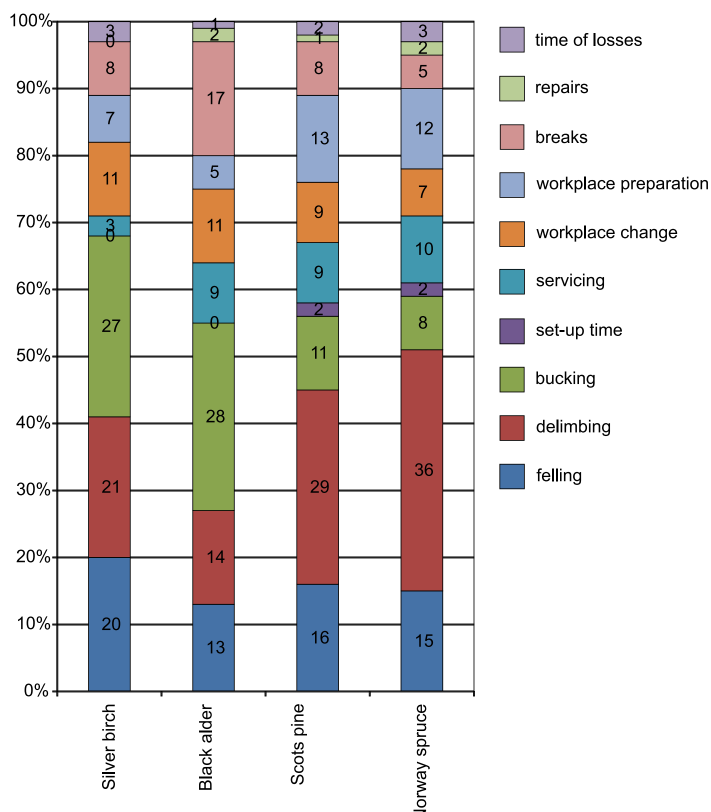

Figure 2. Percentage share of time of particular operations related to cutting and tree processing

Table 1. Time use coefficients, labour productivity, environmental impact

	silver birch	black alder	Scots pine	Norway spruce
General work shift time use coefficient	0.68	0.55	0.56	0.59
Working time use coefficient	0.86	0.81	0.82	0.85
Operational time use coefficient	0.86	0.84	0.86	0.90
Technical-technological robustness coefficient	1.00	0.96	0.99	0.97
Technical maintenance robustness coefficient	0.96	0.86	0.83	0.83
Operational productivity (m^3 h^{-1})	10.4	11.3	15.2	6.2
Working productivity (m^3 h^{-1})	10.0	9.6	13.2	5.2
Exploitation productivity (m^3 h^{-1})	8.1	7.4	9.9	4.1
Energy input (MJ m^{-3})	8.26	3.87	2.48	5.01
CO_2 emission (kg m^{-3})	0.55	0.25	0.16	0.32

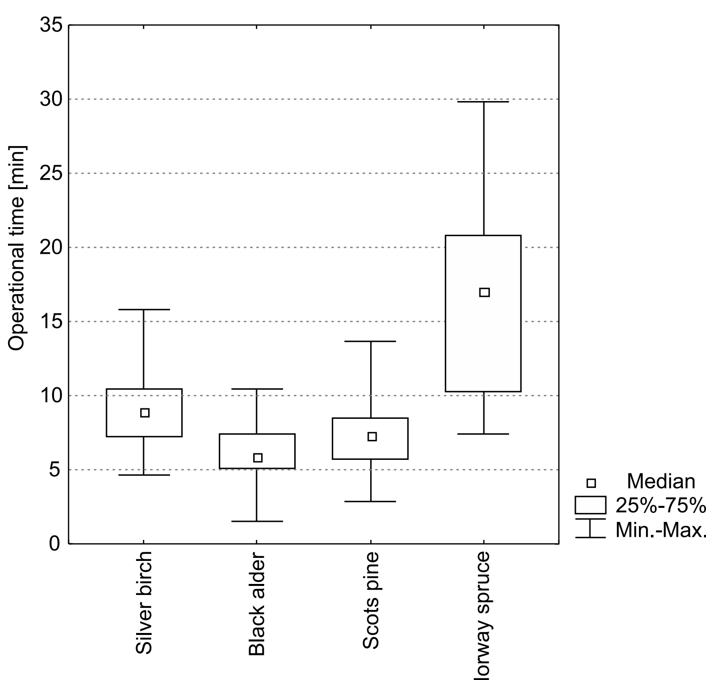

Figure 3. Operational time (felling, delimbing, bucking, change of workplace)

operations was determined. Operational productivity was the most strongly correlated to the mass of tree, while the correlation coefficient ranged from 0.44 in the case of black alder to 0.74 in the case of silver birch. Operational time was also related to mass of tree – in this case, correlation coefficient ranged from 0.66 for silver birch to 0.94 for Norway spruce, but only 0.34 for black alder. Similar, but a slightly weaker, relation occurred between operational time and middle diameter of trees. Time of workplace preparation was weakly correlated to diameter at breast height (from 0.25 in the case of silver birch to 0.45 for Norway spruce) and felling time was slightly more (from 0.27 for black alder to 0.67 for Norway spruce). Delimbing time was correlated to diameter at breast height (from 0.24 for black alder to 0.81 for Norway spruce) and middle diameter (from 0.36 for black alder to 0.87 for Norway spruce) more than with stem's length. Bucking time was slightly

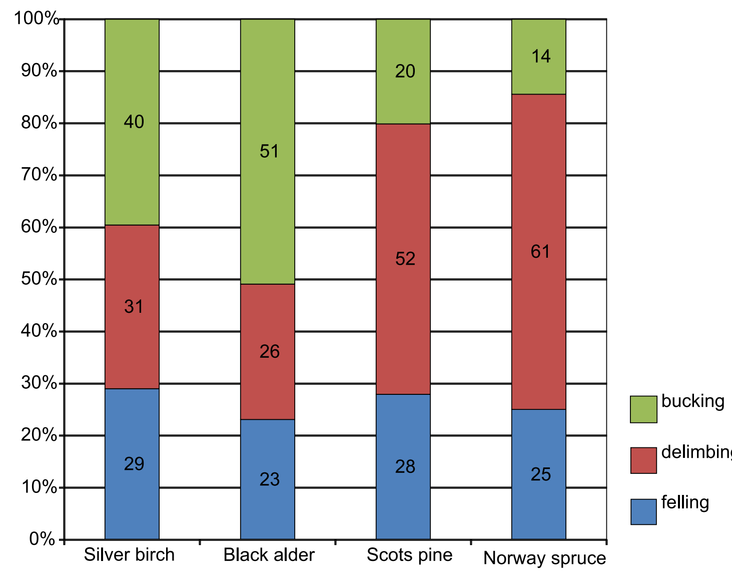

Figure 4. Percentage share of main times in reference to tree species

correlated to trees attributes: correlation coefficient with middle diameter ranged from 0.24 (black alder) to 0.45 (Norway spruce) while for silver birch the coefficient was negative (-0.12).

5. Discussion

The predominant share of bucking time in the case of harvesting deciduous species resulted from the necessity of bucking in certain multiples of length. It significantly influenced the process's efficiency and caused frustration of operators.

A large share of delimbing time, especially in the case of coniferous trees, resulted, in some way, from equipment that was used for work – all lumberjacks claimed that using smaller chainsaws for delimbing (instead of using the same, strong but heavy, which was used for felling) would reduce physical fatigue and increase productivity. That would also reduce the fuel consumption (Więsik and Wójcik 2007). The share of main time and share of breaks in the case of Norway spruce were similar to those reported by Sowa et al. (2006), although the terrain and stand conditions of conducted studies were different. Proportions on main times share for Scots pine are similar to results obtained by Wójcik (2007) (Figure 4).

Due to difficult terrain conditions on the site of ash-alder forest, workplace change lasted slightly longer than on sites of fresh mixed coniferous forest or fresh mixed broadleaved forest; however, because of the rush of lumberjacks (and disrespecting of safety rules) the time spent on workplace preparation in the cases of silver birch and black alder was significantly lower than for Scots pine and Norway spruce. Workplace preparation before felling coniferous trees, taking about 12% of time, required debarking of stems with a diameter often exceeding 50 cm in the place of a cut, which resulted in a great share of this operation, despite a slight snow cover. Lack of stem barking could lead to an increase in the share of service time (including sharpening chainsaws) and increase of fuel consumption. It is worth noticing that due to hard and frozen bark, lumberjacks did not debark birch stems, which influences consumption of fuel (twice as much as for black alder). Low correlation indicators between average mass of tree and workplace preparation time confirm the observations of Gomuła (2004) that time significantly depends on terrain conditions and felling area preparation.

Fuel consumption ranged from 0.07 l m^{-3} for Scots pine to 0.24 l m^{-3} for silver birch that refers to the process's energy consumption respectively from 2.48 MJ m^{-3} to 8.26 MJ m^{-3}, while the share of lumberjacks' energy expenditure ranged from 2% (silver birch) to 6% (Norway spruce). Fuel consumption for Scots pine was close to the one obtained by Więsik and Wójcik (2007), but lower than reported in the study of Kusiak et al. (2012).

Observed CO_2 emission was lower in most cases (apart from silver birch) from emission reported by Giefing et al. (2012). This was due to working conditions at the final felling area and big dimensions of trees, which had a positive influence on work efficiency and caused low fuel consumption.

Low failure rate of equipment, reflected by very high technical and technological coefficients, arises from lumberjacks' investment in modern, professional equipment and high quality tools. None of the chainsaws used was older than 2 years. This led to reduced time of losses and increased productivity. However, frequent breaking of felling wedges was observed – on average, there was one wedge lost on every 26 m^3 of logged timber.

6. Conclusions

The greatest percentage share in total work time for coniferous species was delimbing (Scots pine 29%, Norway spruce 36%), while in the case of deciduous species it was bucking (silver birch 27%, black alder 28%).

Lumberjacks' work productivity depended on the logged species. The greatest operational productivity of lumberjacks was gained while logging the Scots pine (15.2 m^3 h^{-1}), while the lowest while logging the Norway spruce (6.2 m^3 h^{-1}).

Operational time of logging work was most correlated to mass of logged trees, while workplace preparation time was slightly related to diameter.

The share of lumberjacks' energy expenditure in total energy input was low (up to 6%).

Acknowledgements

I would like to thank the Regional Directorate of State Forests in Białystok for the support in conducting this study and enabling the presentation of results during the Forest Biomass Conference (Mierzęcin, 2013).

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Translated by: Tymoteusz Niemiec