Analysis of Accuracy of Evaluating the Structure of a Harvester Operator's Workday by Work Sampling

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Abstract

The study covered an analysis of the accuracy level of measuring time within a working shift using the method of regular snapshot observation at a harvester operator's worksite in Scots pine stands. A conformance level of the analyzed methods was evaluated through assessing the accuracy of rectilinear fitting of time structures, established using the photography of work day method and snapshot observations. The accuracy of snapshot measurements performed in 3-minute intervals was determined as high, exceeding 95%. Increasing the time interval between observations to 10 or 15 minutes resulted in higher estimation error in snapshot observation time, ranging between 5 and 10% for late thinned and clear-cut stands. The accuracy of evaluating proportions of specific work times within a working shift, in regular snapshot observations, was correlated with work cyclicality. The strongest work cycle in thinned stands consisted of 43 activities, with total duration of 13 minutes, whereas in clear-cut stands it comprised 45 activities, with total duration of 15 minutes. One of the advantages of the described method, apart from its lower labour intensity as compared to working day photography, was the possibility to assess labour time and breaks as well as estimate the share of downtime.

Keywords: work measurement, time series, snapshot observation, timber harvesting

1. Introduction

Work measurement is a two-stage examination, including measuring time during work and determining a number of work products after completing the production process. Most methodological errors are made in the first stage, i.e. at determining the time of work. Field research of technology of timber harvesting and skidding are normally conducted within the operational work time, i.e. for activities directly related to the work being done, and then an assumption of their proportions in the entire working shift is made (Backhaus 1990, Sowa et al. 2006, Zečić et al. 2005, Nurminen et al. 2006, Spinelli and Visser 2008). The share of main work time within a working shift is usually estimated based on a labour-intensive time study, i.e. measurement of recurrent work sequences (Szewczyk et al. 2014).

Evaluating the proportions of preparatory and complementary work times is even more troublesome, due to their irregular occurrence. Therefore, they are estimated based on observations of the entire working shift. This method is known as photography of work day (Monkielewicz and Czereyski 1971, Samset 1990, Häberle 1992, Kärhä et al. 2004, Moskalik 2004, Ovaskainen et al. 2004, Picchio et al. 2012, Sowa et. al. 2007, Szewczyk 2010, 2011a). Changeable and complex production processes, typical of forest works, require a suitable measuring method. In this respect, methodologies involving an estimation of frequency of certain activities may appear extremely interesting when many worksites are subjected to investigation, in particular, at early stages of labour research (Szewczyk 2014b).

The method of snapshot observations was introduced into studies on work in industry as early as in

1930s. The grounds for this methodology, called »snap-reading«, were established in 1927 by the British statistician, Tippett (1935). Work analyses performed on similar basis were described as »ratio-delay« (Morrow 1957) or »work sampling« (Brisley 2001), while in Poland they were popularised as »snapshot observations«, at the end of 1950s (Wołk 1960). Work measurement by means of snapshot observations consists in recording events taking place in a constant or varying time interval. The frequency of particular activities encountered at a given worksite translates into a proportion (share) of their durations within the entire time of observation (Wołk and Strzelecki 1993, Szewczyk 2014a). An essential problem recognised for the method in question is determining the time interval, within which the measurements should be taken. This paper presents an analysis of the possibility to extend the time interval between snapshot observations in work sampling at timber harvesting. Such methods have already been applied in forestry sciences, though they still require thorough testing under varied conditions of logging operations (Miyata et al. 1981).

The research aimed to assess the possibility of increasing the time interval between snapshot observations recorded at a harvester operator's worksite and determining their accuracy in various time intervals. The reference point was the time structure of a working shift, obtained using the photography of work day method. In the initial stage of the research, it was assumed that differences would occur in the accuracy of evaluating time consumption for various time intervals in snapshot observations, and that a factor would be indentified related to the cyclicality of work activities and determining the measurement accuracy.

2. Material and Methods

Trial plots were located within the Regional Directorate of the State Forests in Radom, Staszów Forest District (21˚10'E, 50˚33'N), and the Regional Directorate of the State Forests in Łódź, Kolumna Forest District (19˚12'E, 51˚36'N). At these plots, studies of efficiency of mechanised timber harvesting were carried out in 2009–2011, and based on them primary assumptions for methodology of work sampling with the use of snapshot observations were developed (Szewczyk 2014b). The research presented in this paper covered additional, supplementary work measurements. The selected taxation features of the investigated stands were gathered in Table 1.

Wood extraction was mechanised, employing mid-class harvesters Ponsse Ergo (Jiroušek et al. 2007, Dvořák et al. 2011). There were three operators aged 30 to 40, with more than one-year experience. In the course of works performed in the CTL system, the following assortments were bucked: longwood with a length ranging from 8 to 12 m, logged timber

Table 1 Selected taxation features of the investigated stands

Forest district	Cutting category*	Species composition	Age years	Stocking index	DBH cm	Large timber in total m^3/ha	Total removal of large timber m^3/ha
Staszów	CC	Pine 10	87	0.8	27	300	300
	CC	Pine 10	112	0.9	35	336	336
		Oak locally	80				
		Birch locally	80				
	LT	Pine 10	63	1	25	361	75
	LT	Pine 8	63	1	25	280	75
		Oak 2	63		26	56	
Kolumna	LT	Pine 9	62	1	24	323	75
		Birch 1					
	ET	Pine 10	44	1	24	355	46
	ET	Pine 10	54	0.9	22	318	46
	ET	Pine 10	51	0.9	24	300	46

*CC – clear cutting; LT – late thinning; ET – early thinning

Table 2 Flow chart presenting classification of harvester work times. Numerical codes referring to the applied classification were used for constructing time series

WP Workplace time	Main work time	MW	Activity code	1	Pulling out a crane arm, positioning, cutting, felling
					Pulling a tree onto a machine, delimbing, bucking
	Complementary work time	CW		2	Time of relocation around the workplace
					Time of preparing a worksite – removing branches and fragments of logs hindering access to the tree being cut
					Time of arranging logs, sorting bucked assortments
	Maintenance time	MT		3	Time of changing a cutting chain, refuelling, technological adjustments
					Time of unblocking a harvester head, removing branches
	Repair time	RT		4	Times of deleting faults in hydraulic system
	Non-working time	NT		5	Rest time
					Meal time

with a length of 4 m and middle-sized wood in a form of 2.5 meter rollers.

In fragments of the stands, uniform in terms of their taxation features (DBH, height, species composition), work time study was conducted using the photography of workday method (Szewczyk 2011b, 2012, Nurminen et al. 2006, Dvořák and Walczyk 2013). Time measurement was taken automatically by means of PSION Workabout device with »Timing« software, developed especially for chronometric analyses (Sowa et al. 2007, Sowa and Szewczyk 2013). The duration of specific work activities were recorded (accurate to 1 second) and then classified according to the IUFRO standards (Björheden 1991, Dvořák et al. 2011, Szewczyk et al. 2014) (Table 2).

For selecting a homogenous trial sample, the significance of differences in mean time of relocation around the workplace area was tested. From the chronometric sequences, chosen in the above-described manner and obtained by means of the photography of work day method, time categories, theoretically observed in snapshot observations, were sampled. Testing was performed for 3-, 5-, 10-, 15-, 20- and 25-minute intervals between subsequent observations. A simple correlation between percentages of specific time categories from the above-mentioned database was computed and used as the measure of conformance of time structures, determined with the use of both methods, photography of work day and snapshot observations. Since the research covered an analysis of a linear model without an absolute term, a directly proportional relationship between both of the variables was put to the test. Two measures of fitting accuracy were assumed: a coefficient of regression and a coefficient of determination, with error rate at 5%.

The accuracy of work time measurement, assessed with the use of snapshot observations in the given time interval, was correlated with the cyclicality of work activities. This cyclicality was determined through displaying the measurement data as time series, i.e. a sequence of observations for a certain variable in a constant time interval (Box and Jenkins 1976). For converting the chronometric sequences recorded at the investigated worksites into time series, particular observations were encoded using the notation presented in Table 2. Such constructed time series contained the names of respective activities expressed as numerals and playing the role of an observed variable, while the succession of activities (work sequencing), typical of a certain worksite, became an ordering variable (Szewczyk 2011a, Szewczyk et al. 2014, Szewczyk 2014a).

The difficulty in adjusting the method of time series analysis to the investigated phenomenon consisted in the fact that particular cases (observed work activities) did not occur in a stable time interval. For displaying the results of time study, conducted at the selected work sites, in a form of time series, successive observations were encoded according to the scheme presented in Table 2. Thus, the occurrence of sequences of work activities was considered as time series, where individual activities, with their names encoded as numbers, were an observable variable, while the succession of activities typical of the analyzed work sites (work sequencing) constituted an ordering variable (Szewczyk 2011a, Szewczyk et al. 2014, Szewczyk 2014a).

Since the examined time series revealed random fluctuations, their moving average (of equal weights) was smoothed. Time series, in contrast to random samples, are characterised by a non-accidental order of observations. This attribute was used in the present study. The simplest examination of sequencing of certain observations is based on identifying regular fluctuations, i.e. with fixed lengths (expressed by a number of observations), determined as seasonal fluctuations. This simplified approach was assumed by Szewczyk in his studies on establishing the length of work cycles of forest machines. With regard to work sites characterised by a great variability of work (e.g. at timber harvesting or skidding), the length of stable and recurrent fragments of a workday was difficult to determine. In fact, the structure of work time succession at work sites related to timber harvesting and skidding indicated an occurrence of two overlapping work cycles with various lengths. For detecting a variable of this cyclical structure of the investigated time series, methodology of the single-band Fourier analysis was employed (Kot et al. 2007, StatSoft Inc. 2009).

Lengths of recurrent work cycles were estimated based on the entire measurement database. The operation of cutting a tree was assumed as the beginning of each cycle, whereas its total duration was a sum of durations of successive activities, the number of which determined the total cycle length. The beginning of next cycle was marked with another cutting operation.

During the field research, nine working shifts were measured, three per each category of operation. The measurement database contained 10,193 records documenting durations of the distinguished activity categories, while the measurements were taken continuously within more than 86 hours. An analysis of homogeneity of the research sample was performed based on the variance analysis of the time of relocation between successive worksites. The obtained chronometric sequences did not reveal statistically significant differences in respect of the mean value of relocation time; therefore further study was carried out using the entire measurement sample.

The tested database for snapshot observations enclosed 731 records for early thinned stands, 589 for late thinned ones and 652 for clear-cut stands.

3. Results

The lowest share of operational work times was recorded in early thinned stands (0.63), where work

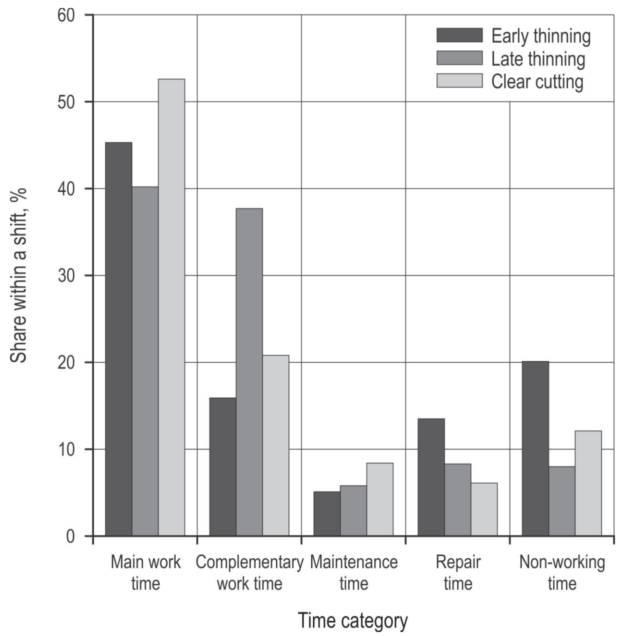

Fig. 1 Time structure of a harvester working shift

conditions were far more difficult when compared with those of late thinnings. The graph in Fig. 1 presents the time structure of a harvester working shift.

With regard to stands of all categories, work times within the operational work time, i.e. main work times (40.2–52.6%) and ancillary work times (15.9–37.7%), had the highest share. The fact that over 40% of all activities were those directly related to work proved that the manipulation areas were very well prepared and the training level of operators was suitable. The highest share of ancillary work times was recorded in late thinned stands (37.7%), which was justified by longer time of relocation between subsequent work sites. The share of times of repairs and technical maintenance, in the technological variants under scrutiny, accounted for ca. 10%, while the share of times for rest and physiological needs amounted to 13%. A slightly higher share of complementary work times was recorded in early thinned stands, which may be explained by harder work conditions.

Activity categories in the analyzed time intervals were sampled, with the use of EXCEL spreadsheets, from the entire database obtained by means of the snapshot observation method. Sampling was conducted using the LOOKUP logical function (vector form), which searches for given data in a one-row or one-column range (vector), and returns the value in the same position in another one-line or one-column range.

Table 3 Number of observations in the tested variants

	Early thinned stands	Late thinned stands	Clear cutting stands
Photography of work day, pc.	4229	3129	2703
Observation time interval, min	5	10	15
Snapshot observations, min	399	200	132
Share of snapshot observations,%	9	5	3

Table 3 presents a comparison between databases created using the photography of work day method and those based on the selected variants of snapshot observations.

Table 4 contains the accuracy parameters of the time structure assessment obtained using the snapshot observation method.

The performed analyses demonstrated that the time structures, determined upon application of both of the investigated methods in 3-, 5-, 10- and 15-minute intervals, were very strongly correlated ($R^2\varepsilon \leq 0.70; 0.99 \geq$) (Stanisz 2007). Moreover, the relationship between the time structures for these time intervals was nearly directly proportional ($R\varepsilon \leq 0.86; 1.00 \geq$). Thus, the accuracy of the snapshot observation method for the above-mentioned time intervals was proved to be considerable. In respect of other investigated time intervals, the estimation error was higher.

Fourier spectral analysis revealed an occurrence of overlapping cycles of work activities within the investigated working shifts, differing in terms of their

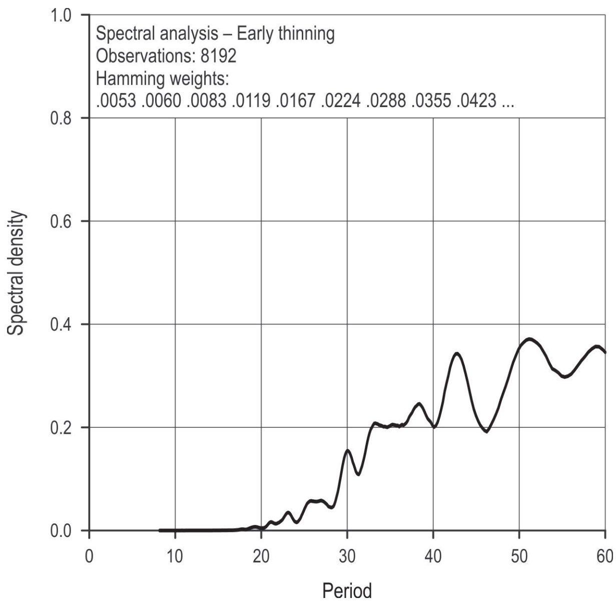

Fig. 2 Fragment of a periodgram of harvester work in early thinning. The highest peak of the periodgram indicates the strongest work cycles

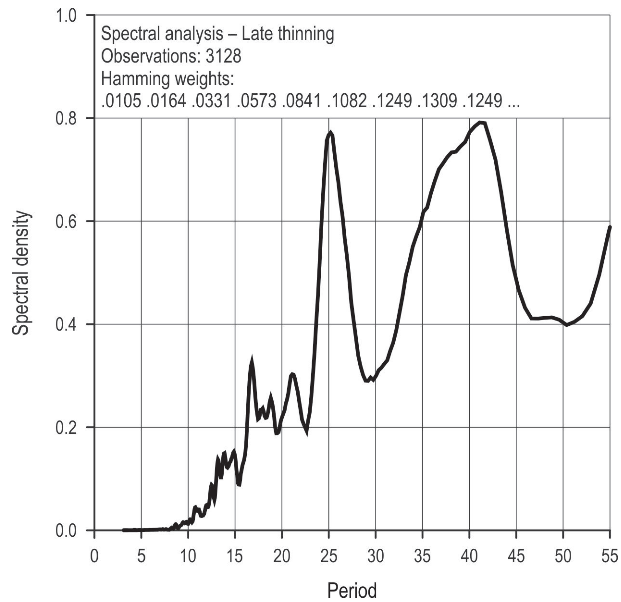

Fig. 3 Fragment of a periodgram of harvester work in late thinning. The highest peak of the periodgram indicates the strongest work cycles

Table 4 Accuracy parameters of the time structure assessment obtained using the snapshot observation method for the selected observation time intervals

	Cutting category, working shift (R^2/R)								
Observation time interval, min	ET1	ET2	ET3	LT1	LT2	LT3	CC1	CC2	CC3
3	0.99/0.99	0.99/1.00	0.99/1.00	0.94/0.87	0.99/0.98	0.96/0.93	0.99/0.97	0.98/0.96	0.99/0.98
10	0.96/0.97	0.98/1.03	0.98/0.98	0.83/0.86	0.97/0.96	0.96/0.94	0.74/0.97	0.99/0.95	0.96/0.91
15	0.93/0.92	0.95/0.98	0.70/1.00	0.93/0.90	0.96/0.94	0.95/0.92	0.73/0.96	0.96/0.90	0.98/1.00

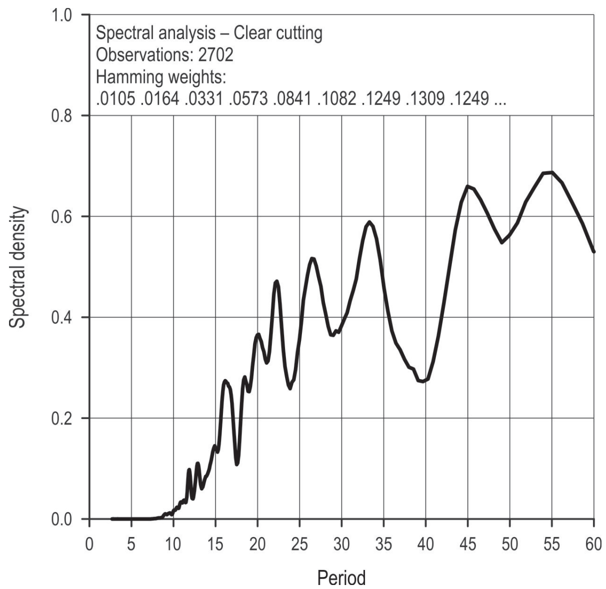

Fig. 4 Fragment of a periodgram of harvester work in clear-cutting. The highest peak of the periodgram indicates the strongest work cycles

lengths. The highest peaks of periodograms, presented in Figures 2–4, were typical of cycles having the strongest impact on the observed general variability (Table 5).

Lengths of work cycles and their durations within the analyzed groups of stands were presented in Table 5. Due to the skewness of distribution of work activity durations, a median value was given as a cycle duration.

With regard to all the investigated stands, the lengths of work cycles were similar, enclosing 43–45 successive activities. Duration of one cycle in thinned stands counted 13 minutes. Whereas, in clear-cut stands, due to longer times of relocation and wood processing, the work cycles were by ca. 15% longer (15 minutes). High accuracy of snapshot observations, presented in Table 4, recorded in longer, 15-minute intervals may be explained by similar sequencing of work.

4. Discussion

Assessing the labour consumption of production processes is based on the proportions of operational times (main work time, ancillary work time), as well as complementary and preparatory times (maintenance time, repair time, non-working time) (Jabłoński 2006, Dvořák et al. 2011). In forestry, due to the great variability of work environment, such studies are usually conducted using the photography of work day method, consisting in measuring duration of all activities encountered during a working shift. This method, though it provides an abundant research material, has many drawbacks. Among others, it requires the observers to be perfectly acquainted with the employed logging technology. Moreover, the measurements involved are extremely time-consuming, which makes the entire investigation very costly. These are the factors due to which the databases obtained in the above-mentioned manner are usually unsatisfactory and insufficient to draw any undisputable conclusions in terms of the general variability of the analyzed phenomena. With regard to harvesters, it would be possible to perform the work time analyses based on the data recorded by their computer systems (Dvořák et al. 2011), though a decrease in precision of such obtained data is likely to occur (Purfürst and Erler 2011).

The method of snapshot observations is an important research tool for analyzing the duration of work activities, in particular, while determining the proportions of non-operational times (SW – supportive work time, NT – non-working time, NW – non-workplace time) within a working shift. Miyata et al. (1981) noticed that the method in question is much more useful than the photography of work day since it enables to observe a few worksites at the same time, which considerably shortens the time of taking measurements. Moreover, it is less tiresome, thus the obtained results are believed to be less burdened with measurement errors. One of the greatest advantages of snapshot observations is the possibility to reduce the size of databases (Miyata et al. 1981, Szewczyk 2014b).

Table 5 Characteristics of a number of activities constituting a work cycle and total duration of the cycle in the investigated stands

Cutting method	Cycle length			
	Number of observations	Cycle length (number of observations) determined in Fourier analysis	Number of cycles, based on which a cycle duration was determined	Cycle duration (median) min
Early thinning	4229	43	96	13
Late thinning	3129	43	118	13
Clear-cutting	2703	45	76	15

An essential problem arising upon applying the snapshot observation method in work measurement is choosing an appropriate time interval, in which the observations are recorded. This is extremely significant while investigating a highly changeable work environment, which is usually encountered at operations of timber harvesting and skidding. The measurement frequency determines the size of the research sample directly. Therefore the simplest solution would be to establish the minimum number of observations, and based on this, to assess the constant or variable time interval of the measurement. This approach was adopted by Miyata et al. (1981) in their studies on harvester operation, making the minimum number of snapshot observations dependent on the standard deviation and the assumed confidence level, both calculated for the primarily taken research sample. The above-mentioned researchers assessed the accuracy of their measurements based on the confidence interval of binominal distribution. A serious drawback in the presented approach was the necessity of assuming one feature arbitrarily (e.g. non-working times) as a reference point for the entire variability, determined by the characteristic structure of all productive and non-productive times.

The snapshot observations, even those recorded at low frequencies and under conditions of great variability of work, typical of logging operations, allow determining the time structure of a working shift very precisely. The results obtained in the course of the studies presented here, at frequency of measurements up to 10 or 15 minutes, correspond to the data recorded for forest machines published by Miyata et al. (1981).

One of the most essential factors that lowers the accuracy of snapshot observations is the conformance of time interval, in which an observation is recorded, and the length of work cycle, in particular, at high recurrence of work operations, which is often encountered, e.g. in industry, on production lines (Wołk 1960, Wołk and Strzelecki 1993, Szewczyk 2014b). The conducted studies proved that the time interval of slightly shorter or longer duration than the one of a work cycle reflects the shares of all activities within a working shift very accurately. Theoretically, one may expect that in such a case sampling would always indicate the very same work activity, making the measurements completely unreliable. However, since work cycles have varied lengths and sequences of various work activity structures overlap one another, the synchronisation between cycle lengths and snapshot observations is practically impossible.

5. Conclusions

Accuracy of evaluating the time structure of a work day employing the method of regular snapshot observations was assessed with the use of coefficients of determination and regression, calculated for a linear dependence between the time structures, determined upon application of the photography of work day method and snapshot observations.

The research covered testing an accuracy of the data obtained in snapshot observations recorded in 3-, 5-, 10-, 15-, 20- and 25-minute intervals. In early thinned stands, high accuracy (max. 5% margin error) of regular snapshot observations was proved for time intervals up to 10 minutes. Assuming the lower limit for values of coefficients of determination and regression at the level of 0.90 (max. 10% margin error) allows to apply 10- or 15-minute intervals also in late thinned and clear-cut stands.

The accuracy of evaluating the proportions of work times within a working shift using the regular snapshot observation method depends, among others, on the ratio of the work cycle length to the time interval between subsequent observations. High accuracy of estimation can be reached providing that the length of work cycle and the duration of time interval are similar, and the measurements are taken at a worksite characterised by great variability of work and overlapping cycles with varied lengths.

Among the advantages of snapshot observations, except for the lower labour intensity of the research than the one required by the photography of work day method, a possibility to assess the shares of complementary and preparatory work times should be named. Furthermore, quick sampling of time within a working shift allows to evaluate a few worksites at the same time.

Acknowledgement

This work was supported by the Ministry of Science and Higher Education of Poland under Grant No DS ZULiD/3412/2014

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Received: September 10, 2015
Accepted: January 11, 2016

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