Selection of time study methods for forest operations

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Abstract: Standardisation of worktime is an essential element used in modern forest management. First attempts of standardisation were developed for the industry. The solutions used in the earliest research have been constantly modified for several decades, in order to adjust them as much as possible to the diversified nature of forest works. The earliest time studies were conducted with the use of manual chronometers. As the techniques and technologies of forest works grew more advanced, the measurement means and accuracy standards hitherto applied appeared insufficient. Introducing video methods into analyses of work processes and application of computer-aided techniques in data processing resulted in a significant decrease in labour intensity of measurements and improved their accuracy. The standard to be achieved in the future is to complement the analyses in question with data generated by the computer operating systems, installed on multi-operational forest machines to control the wood processing.

Key words: work research, time consumption, time study, timber harvesting, timber skidding

METHODS OF WORKTIME STANDARDISATION IN FORESTRY

Standardisation of worktime aims to establish the actual level of time consumption of works to calculate appropriate payment. However, the results of such studies may be useful in many fields of science, e.g. Analysis of work hazards at particular worksites. Standardisation of worktime is conducted at two levels - measurement and estimation. The measurements are taken for effective and ancillary worktimes. Such particular worktime categories are the best determinants of the variability of work conditions at certain worksites, such as: stand characteristics, landform and bearing capacity of soil, etc. (Gil 2007). The main (effective) worktimes are related to operations that have a direct impact on the work subject. With regard to timber harvesting and skidding, these operations are connected with wood processing (felling, delimbing and cross-cutting) or its relocation (skidding, forwarding). The ancillary worktimes cover activities that enable the performance of main works. Based on the measurements of effective worktimes within particular categories, an estimation of ancillary worktimes is drawn, including the time for worksite maintenance and the preparatory worktime (Samset 1990); (Zečić, Marenče 2005); (Vusić et al. 2011); (Sowa, Szewczyk 2013).

Standardisation of worktime is done using cumulative and analytical methods (Monkielewicz, Czereyski 1971); (Szewczyk 2014) (fig. 1). Cumulative methods are used for determining standards of worktime for the entire operation. They operate both, solid experience and expertise of the investigator. There are three methods distinguished within this group:

1. statistical method, where the standard is determined based on statistical data gathered in previous years;
2. method of estimation, where the standard is determined based on an evaluation drawn by a qualified and experienced specialist;
3. comparative method, where the standard is determined through comparison with analogical or similar works, for which the standards of worktime have already been established.

Analytical methods enable the investigator to analyse the entire production process or its fragment, and determine the manner of work organisation suitable for certain work conditions. Within this group, analytical and
computational, as well as analytical and exploratory methods can be distinguished (Nuutinen et al. 2006):

1. with regard to the analytical and exploratory method, worktime measurement is taken directly on a worksite. The measurement covers all elements of work. Although the method is very labour-intensive and time-consuming, it provides an abundant research material;

2. with regard to the analytical and computational method, determination of worktime is based on the current standards of worktime established for particular elements of work, such as the time required for preparation and completion of work or maintenance of a worksite, as well as the time for rest and natural needs.

Taking into account the above mentioned aspects, measuring the duration of particular activities is an integral component of all worktime-related standardising processes.

METHODS OF WORKTIME MEASUREMENT

The worktime measurement comprises more than just the activities directly related to recording the duration of particular actions. In fact, such an analysis is performed in several phases, which also include a determination of the research aim and an optimisation of technological solutions and work techniques employed by a machine's operator (Ovaskainen et al. 2004). There are three general methods of worktime measurement:

1) continuous - covering the entire working shift (photography of a workday);

2) cyclical - covering parts of the process, e.g. time between cutting a tree and processing timber assortments (time study);

3) random - covering a part of a working shift, distributed systematically within the entire worktime (snapshot observation).

However, more developed divisions of methods used in work time measurements are also proposed (Wolk 1960); (Szewczyk 2014 a) (fig. 2).

1. Time study

Time study is based on measuring the duration of recurrent elements of work (Kazalski 1964); (Kanaway 1992); (Szewczyk 2014). In general, this method was developed for analysing time consumption at worksites characterised by the work cyclicality. A good example of such worksites are those, where operations are performed by multi-operational machines (Szewczyk, Sowa 2011), (Szewczyk, Sowa et al. 2014). Theoretically, these are the operations of cyclical nature. With regard to timber harvesting performed by a harvester, a single work cycle includes the following activities in a given chronological order: running a chainsaw to execute a kerf, cutting a tree, felling, delimbing and cross-cutting, relocating a machine or reaching the next tree with a crane. Measuring the duration of a cycle is stopped as a chainsaw is run to cut another tree, which marks the beginning of another cycle.

According to the IUFRO classification (IUFRO 1995), three chronometric methods are recommended:

1) cumulative timing - cumulative duration of operations (Nurminen 2006); (Szewczyk 2011); (Dvořák et al. 2015),

2) check study – determining the size of a trial sample,

3) snap-back timing – determining the structure of worktime based on measuring the duration of individual elements of work (Jourgholmi et al. 2013); (Yoshima, Sakai 2015).

Fig. 2. Research methods used in work time measurements

2. Photography of a workday

The photography of a workday method is based on recording the course of a workday through measuring the duration of all events within the work process performed at the selected worksite, including periods when no activities are undertaken, in a chronological sequence ordered by their occurrence from the begging of work until its completion (Wolk 1960); (Strzelecki 1983); (Laitila 2012); (Nuutinen 2013). In worktime-related terminology developed by the IUFRO (1995), there are expressions referring to this method, such as overall study, timing. Therefore, the method in question should be considered a valuable source of information on time consumption of work and its organisational structure. The photography of a workday is also employed to capture any loss of time and compare the duration
of actual work with the duration of breaks (Rypulak 1980).

A considerable drawback in employing this method for measuring worktime is the fact that it is considerably tiresome and labour-intensive, due to which the studies are usually limited to few working shifts merely (Szewczyk, Kulak 2013). It is noteworthy that taking measurement for many hours requires the investigator to stay extremely focused and concentrated throughout the entire day. This often causes errors in recording the exact moment when activities actually change. The excessive concentration may also result in distraction of the observer who is likely to neglect a change in the nature of a certain activity, which significantly affects the accuracy of measurement. These phenomena are of particular importance for measuring worktime at worksites where activities change very quickly, such as those engaging multi-operational machines (Palmorth 2011).

**Individual and collective photography of a workday**

In practice, the method of photography of a workday can be applied in two variants: an individual or a collective photography, where the nature of work performed at a certain worksite, individual or collective, is the major criteria in this division. The individual photography of a workday is employed when the work under analysis is performed by one worker. Analysing the work done by one person provides detailed data, though within a very small range. The data obtained can be used for characterisation of only one worker, with certain psycho-physical features. Whereas, the collective photography of a workday delivers data obtained through an observation of activities performed collectively, by a group of workers, therefore such data may be considered "averaged" for a certain worksite and a certain work team. The collective photography aims to determine a mutual relationship between the duration of actual work and breaks, as well as to gather material, based on which the reasons for taking breaks during the work can be identified. The accuracy of the collective worktime measurement depends on the number of workers under investigation. This method enables a precise determination of loss of time at the particular worksite. It is also a fine source of information that can serve for establishing standards of worktime and comparing work performance of several workers.

**Photography of a workday "along the route"**

The method of photography of a workday "along the route" is similar to the method of collective photography. The difference is that the investigator is not focused on one worker merely, instead he moves along the route established between the particular worksites, within a given time of relocation. When employed in the industry, the number of workers under observation amounts to ca. 20, within 3- or 4-minute intervals. The analysis covers recording the duration of work-related activities (general record) and breaks (detailed record) (Kazalski 1964). With regard to work research in forestry, the method in question can be used for investigating mechanised logging technologies that engage harvesters and forwarders (Szewczyk 2014 b).

**Self-made photography**

The method of self-made photography does not require involving an outer observer in the investigation since the person under analysis can record the duration of his work by himself. All it takes is a brief training, after which a worker is able to collect data on his own. However, the usefulness of data obtained in this manner is determined by an approach of the worker-investigator towards the aim of the research (Wolk, Strzelecki 1993). While it is true that this method cannot be directly applied to investigate particular worksites in forestry, questionnaire surveys, which have been carried out recently to verify estimated shares of complementary and preparatory worktimes, may be considered a certain kind of self-made photography (Szewczyk, Sowa, Jamrozik 2015).

**Snapshot observation method**

The method of snapshot observation is alternative to the classical photography of a workday. Studies on worktime using the snapshot observation method are based on recording work events within a constant (regular observations), or changeable and incidental (irregular observations) time interval (Miyata et al. 1981); (Szewczyk 2014 b). In the IUFRO terminology, snapshot observations are referred to as work sampling and frequency study. Summing up the number of observations of certain activities performed at the worksite under analysis, makes it possible to determine proportions (shares) of their durations within the entire time of the investigation (IUFRO 1995). Taking into account the work variability typical of worksites where timber harvesting and skidding are done, an appropriate selection of time intervals, within which the observations are made, is of crucial importance.

**WORK VARIABILITY IN FORESTRY, ERROR MEASUREMENT**

The major issue in measuring time consumption of work is constructing stable and uniform measurement databases. Specific work conditions encountered in forestry determine a great variability in work efficiency, which is noticeable not only within stands but also within particular worksites. Among determinants
of the work variability in question, environmental factors are usually named, such as stand characteristics, terrain conditions and logging technologies, whereas the human factor is often neglected. In principles, work should be performed using optimal capabilities of a worker, including an adequate level of specialised skills. His varying readiness to work results from natural tendencies of a human organism to adjust its psycho-physical efficiency to the effort required. The level of human's work efficiency is also determined by weather conditions, e.g. temperature. Moreover, fluctuations in work efficiency are due to human's nature and changeable work conditions. Therefore, an objective assessment of the above-mentioned features is very complex and troublesome (Strzelecki 1983).

Before commencing worktime measurements, especially in forestry, information concerning a worker and weather conditions have to be provided: an accurate recognition of skills, professional experience, and psycho-physical state of a worker, as well as an identification of the weather and climatic conditions encountered at the worksite under analysis. This data is recorded in databases designed especially for this purpose, which enables the investigator to establish a reference point used in comparison with the data collected.

The above-mentioned work variability makes it necessary to determine the possibility of occurrence of estimation error. A primary assumption is that a worker performs his work with a permanent efficiency. Nevertheless, the actual values of measured worktime are expected to reveal a certain dispersion due to incidental fluctuations in executing particular movements, or small differences in location of a work object or tools, or finally, false reading of the results (Strzelecki 1983).

To reduce the risk of occurring significant measurement errors, caused by changeability of human's work, skills of the person recording the results, and the accuracy of measuring devices, a determination of the size of a measured sample is essential. Due to possibility of emerging variations in the duration of a single activity, establishing a minimum number of observations is crucial, so the measured values would reflect the actual labour intensity as accurate as possible. Increasing the size of a trial sample improves the accuracy of reasoning to some extent; however, if it reaches above a certain value, the error will not decrease significantly. Therefore, the number of measurement repetition greater than that assuring an acceptable error level seems unreasonable.

The number of chronometric observations essential for keeping the error at the acceptable level is determined with the use of the Student's t-test random variable for a series of primary measurements, which are then included in the general database (Błasiak 2000).

\[ n = \left( \frac{100 \times t \times S}{\varepsilon \times x} \right) \]

where:
\( n \) – number of necessary chronometric measurements,
\( t \) – value of the Student's t-test random variable for primary measurements,
\( S \) – standard deviation for primary measurements,
\( \varepsilon \) – relative estimation error (%), \( \varepsilon = (\Delta/\bar{x}) \times 100 \),
\( x \) – mean value of primary measurements.

Regarding the fact that chronometric sequences may require data cleaning (removing outliers), the number of measured work cycles should be increased by ca. 15%.

While taking measurements using the method of photography of a workday (recording all categories of activities), the necessary number of observations can be determined by means of equation:

\[ n \geq n_0 = \left[ \left( 1 - \frac{\alpha}{2}, n-1 \right) \frac{S^2}{t} \right] + 1 \]

where:
\( t \) – Student's t-test array value,
\( S \) – standard deviation estimated theoretically based on the duration of all the categories of activities encountered,
\( l \) – half of the confidence interval, e.g. 3 sec.,
\( \alpha \) – significance level 0.05 (5%),
\( n_0 \) – limit size of a sample

Taking into account the above-mentioned great variability of work in forestry, the recommended databases should contain more than several thousand observations (Szewczyk 2014 a). For instance, according to Szewczyk (2014 a) assuming the measurement error at the level of 5% and depending on the diversification of activities recorded at particular worksites, the minimum number of observations should amount to:

1) ca. 20,000 for a sawman working at cutting and felling of trees,
2) ca. 4,500 for a sawman working at manipulation and cross-cutting of trunks,
3) ca. 15,000 for ground skidding of timber,
4) ca. 6,500 for processor operations.

MEASUREMENT OF WORKTIME

The beginnings of studies on worktime in forestry were connected with many attempts to standardise worktime, which were undertaken in the 1960s. Four
main methods of taking measurement of worktime in forestry were in use (fig. 3).

Fig. 3. Types of worktime measurements in forestry

Introducing innovative machines into forest practice contributed to an increase in the pace of works. However, it also transformed the structure of work into sequences of activities that changed very quickly, which made it difficult to record their duration precisely. This forced the investigators to engage computer-aided measurement techniques in a form of applications installed on mobile microcomputers or on-board computers of innovative, multi-operational machines.

1. Manual measurement of worktime by means of a chronometer

The simplest manner of measuring worktime involves wrist chronometers or regular wristwatches, which have been used in time studies since their very beginnings. Regarding that the accuracy level of measurement acceptable in forestry is 1 second, the devices in question met this requirement sufficiently (Porter 1992); (Pilarek 1996). Their great availability and low purchase cost made them suitable for time studies, which has not changed until present, though mechanical chronometers are successively replaced by digital models. Techniques of worktime measurement taken with the use of chronometers were quite complex and they employed various types of devices for four different kinds of measurement (Strzelecki 1983):

1) single-event measurement, where a single, separated element of an operation was measured;
2) on-going measurement, where the timing started as soon as the work began, and when the activities changed, the moment of change occurrence was recorded;
3) coupled single-event measurement, for which two mechanically combined chronometers were used. One of the chronometers was activated as the other was paused, which gave the investigator enough time to write down the readings;
4) coupled on-going measurement, which resembled the above-mentioned method in principle, however, this type of measurement was taken by means of double chronometers, with two hands, either of which could be paused independently.

The major issue in taking worktime measurement with the use of chronometers was the necessity to control the manner of work performance (changes of activities), operate a chronometer, and manually record readings, all at the same time (fig. 4). This inconvenience resulted in frequent errors, caused mostly by delays in recording the exact beginnings of successive activities, and mistakes at classifying certain activities. Another problem was related to transferring data from field logs into final spreadsheets, which was done manually.

Fig. 4. Model of a pad used for writing down readings of a chronometer (acc. to: Wolk and Strzelecki 1993)

2. Manual measurement of worktime with semi-automatic recording using a manual chronograph

Chronographs were machines that recorded the duration of observed activities on paper bands (fig. 5). The device in question marked points in time when particular activities started. Marking of these points was done manually by an investigator, who pushed
a respective trigger and the device started to draw a line on a paper band, which moved automatically at permanent speed. The lines drawn on the band represented the duration of respective activities. Dotted lines, created through an appropriate manipulation of triggers, reflected the beginning and the end of successive activities, while the length of particular sections referred to the duration of those activities. Adjusting the speed, at which the tape moved, made it possible to record shorter (at lower speed) or longer (at higher speed) duration of particular activities (Strzelecki 1983). Chronographs were not used for worktime measurement in forestry.

3. Manual measurement of worktime with automatic recording using an automatic chronograph and electronic devices

In order to eliminate difficulties due to time-consuming reading of results marked on a paper band, the devices described in the previous sections have been modernised. Electronic chronographs made it possible to record the mean duration of activities. They also enabled recording five categories of activities at one time, including their mean duration and a number of observations (fig. 6). The device started to measure the duration of an activity automatically, upon a user pushing a button assigned for a certain worktime category. Results were recorded as a sum of all worktimes within a given category. Moreover, the chronograph recorded a number of measurements taken for every category of activity, as well as the total number and duration of all measurements. Another type of an automatic chronograph was a device recording data without an active involvement of the investigator. The recorder was connected with a machine that performed the work (Strzelecki 1983).

![Data card used for recording duration of particular elements of work](image)

Fig. 5. Data card used for recording duration of particular elements of work:
A) Peiseler chronograph,
B) Biegeleisen-Kreiser's chronograph
Worktime measurement using microcomputers and devices with the Android operating system

Time studies require an excellent precision and involve several persons to take the measurement, which is particularly true for investigating work processes characterised by a greater work variability. Therefore, in the research practice of the recent years, algorithms cooperating with mobile computers have been developed to optimise measurements and calculations. Since the beginning of the 1990s worktime analysis has been performed using mobile devices, equipped with a software assuring an efficient conducting of time studies (Mussong 1990); (Samset 1990); (Błasik 2000); (Suhomel et al. 2006); (Eliasson et al. 2015). With regard to forestry, the studies on worktime engaged PSION recorders, commonly used in the State Forests in Poland, and equipped with the "Timing" software, which was developed especially for recording the duration of particular operations (Sowa et al. 2009); (Sowa 2013) (Fig. 7). The above-mentioned software is flexible enough to allow the investigator to design the structure of operations encountered at the worksites under analysis, or the types of activities performed, as early as at the stage of setting configuration of the PSION device, which is done before every measuring session. The device provides fast transfer of data containing all the information about the measurements in a format compatible with the EXCEL spreadsheet, which makes it possible to create and maintain large databases that in certain cases may contain even a few hundred records for a single working shift.
Very promising in this respect are new applications that have appeared at the market recently, among which one can name those developed for iPhones and iPads offered by the AppStore platform, or for mobile phones with the Android operating released by Google Play. An exemplary solution is an application for time measuring – REFA Zeit, which allows the user to take simple, cyclical measurement of time, according to the REFA method. A professional version of the software in question is practically unlimited in terms of its capacity to process any measurement data, regardless its duration and quantity. Another simple research tool, available at the current market, is the Timer Pro software developed for devices with the Android operating system. This software is a great support for the KAIZEN teams in their research on the improvement of work processes.

Worktime measurement using the video footage

Worktime research conducted at worksites characterised by a great recurrence of worker's movements can also engage methods of imaging duration of elementary activities that last less than 0.01 - 0.03 minutes. Such methods usually involve video recording at a fixed speed (Strzelecki 1983).

Development of the methods using the video footage (MTM – Methods Time Measurement) was based on a phenomenon, observed by A.D. Segur in 1927, that the time required for performing basic movements by various workers, yet acting in the same manner, is a fixed (Sajkiewicz 1981). Particular elements of those movements can be distinguished and summed up. This allows the investigator to define standards for quickly recurring activities encountered at worksites where the work performance involves human's sight (eyeball movements), significant contribution of arms and hands (gentle, precise actions, e.g. tasks in seed assessment stations or office work), or a torso and lower limbs (e.g. tasks related to sorting seedlings) (Sajkiewicz 1981). At the market there are also available modern systems for analysing video footage, such as the above-mentioned Timer Pro software developed by the Applied Computer Services Inc., USA. The Timer Pro software allows the user to perform a number of optimising analyses automatically, among which the analyses of work standardisation, Pareto, SMED, line balancing and Yamazumi can be named (fig. 8, 9).

4. Worktime measurement with automatic recording

Modern multi-operational machines (harvesters) used in timber harvesting make it possible to take the worktime measurement by means of automatic measuring systems (tab. 1). An analysis of this type requires a controlling and measurement standard, e.g. StanForD, which was elaborated in the 1980s and has been applied until present (Dvořák et al. 2011). Due to possible low accuracy of data obtained in this manner, recording the duration of particular activities is often performed with the use of micro-computers, which particularly concerns worksites characterised by a great variability of work (Szewczyk, Sowa, et al. 2014). As it was stressed by a few authors, this method of taking measurement provides a large number of measurement data, which is very useful, e.g. for analysing work techniques applied by machine's operators (Purfürst, Erler 2011). Upon activating a measurement program, a computer installed on the machine measures the duration of every operation performed by the machine during a single working shift (photography of a workday). In addition, the volume
of processed wood is recorded, which is essential for elaborating algorithms that describe the efficiency and time consumption of work (fig. 10). However, an automatic measurement of wood volume may be burdened with an error difficult to assess, resulting from an inappropriate calibration of measurement systems installed on processing heads of the machine, which are responsible for recording lengths and diameters of the wood handled.

**DISCUSSION AND CONCLUSION**

Attempts to create uniform standards of time consumption of work were made in the 1960s, when the Directories of labour intensity of work were introduced into practice. Since that time they have been repeatedly updated as regional, binding documents issued by the Regional Directorates of the State Forests. They were usually drawn based on cumulative measurement methods, using payroll documents of the previous years as input data. This solution was effective for non-advanced work technologies of those times. Forest management carried out by the State Forests in Poland complies with the rules of economic account, therefore identifying factors that actually shape the costs of forest operations are extremely important.

The current Directory of labour intensity of forest works has been in force since 2004 (Zarządzenie nr 99... 2003 ). It was introduced as one of the elements taken into account in financial and economic planning of forest management performed by the State Forests. Nevertheless, due to intense technological advancement (Mederski et al. 2016) those directories became outdated very quickly. On the initiative of the Directorate General of the State Forests they have been updated recently, with the use of calculation and measurement methods. Determining the actual time consumption of work is now based on field measurements using the methods of photography of a workday and time study. There were also attempts to implement new solutions in measurement techniques and work standardisation methods that involved accurate field measurements based on recording all events during the entire workday, and combined with statistical analyses. Nevertheless, this will require detailed analyses aimed at establishing accurate categorisation systems for work conditions at timber harvesting (Stampfer and Lexer 2001); (Kangas et al. 2002); (Szewczyk 2009); (Skoupý 2011).

Innovative technical and technological solutions developed in timber harvesting and skidding, and evolving rules of forest management provide the practice of forest works with technologies engaging methods differing from the traditional ones and changing the nature of works, which consequently affects the level of their labour intensity. Technological progress in forestry stimulates the necessity for successive adaptation of tools used in work study and worktime standardisation. Identifying respective research methods, employed in the past and presently, should serve for optimisation of measurement methods, especially while investigating worksites characterised by a great variability of work, like those encountered at timber harvesting and skidding.
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