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Evaluation of total time consumption in harvester technology deployment in conditions of the forest sector of the Czech Republic

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Abstract

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Cut-to-length technology represents a modern forest logging technology characterized by high performance, efficiency, productivity and work safety. At the same time it is friendly to forest ecosystems. Both acquisition and operating costs of harvester units are high, which requires their year-round utilization. The aim of this paper was to analyse shift time consumptions and thus analyse the common harvester and forwarder work shift. In 2015–2016 we collected time snapshots of harvesters and forwarders of various performance categories and from different production conditions throughout the Czech Republic. Consequently the analysis of work shift time with respect to unit, batch and shift times was conducted. The average duration of a harvester's work shift was 623 min, out of which operational time amounted to 73.6%. In forwarders the average shift took 520 min, with operational time representing 71.2%. In the course of the analysis and statistical data processing, all the remaining shift times which constitute an average harvester and forwarder work shift were quantified in detail. Work shift utilization ranged from 86.1 to 95.3%.

Keywords: shift times; harvester unit; work productivity; work efficiency; forest harvesting

Cut-to-length (CTL) technology is a modern forest harvesting technology characterized by high performance and efficiency (Nakagawa et al. 2007; Dvořák et al. 2012; Erber et al. 2016), safety and work hygiene (Malík, Dvořák 2007; Gerasimov et al. 2013; Aalmo, Baardsen 2015), which at the same time enables us to reduce harvesting and forwarding costs (Gerasimov et al. 2013; Erber et al. 2016) and, when compared with other technologies, generally plays a positive role in mitigating the negative impacts on forest ecosystems during logging and forwarding.

Considering the increased number of harvesters and forwarders deployed in the forest sector, it is imperative that we are well aware of the possibilities and conditions for achieving maximum or optimum performance of the harvesters and forwarders and operating technology as a whole. This has been the subject of a number of studies to date (Nurminen et al. 2006; Dvořák 2007; Jiroušek et al. 2007; Dvořák et al. 2012; Slugeň et al. 2014; Aalmo, Baardsen 2015; Erber et al. 2016; Lazdiņš et al. 2016; Mederski et al. 2016). The basic information necessary for determining harvester performance is work separated into individual work elements whose duration, or the duration of its segments, is then recorded (Dvořák et al. 2012; Palander et al. 2012; Erber et al. 2016;

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Lazdiņš et al. 2016; Mederski et al. 2016). Most papers focusing on this topic primarily deal with work performance based on evaluation of operational time, while non-productive time (shift and batch time) and loss time are evaluated as a whole without any further differentiation. General evaluation of shift time, including a detailed differentiation and quantification of non-operative and loss time, is the focus of work e.g. by Nurminen et al. (2006), Dvořák (2007), Dvořák and Keivan Behjou (2011), Slugeň et al. (2014), Olivera and Visser (2016) or Szewczyk et al. (2016). More comprehensive research which would deal with total time consumption during a work shift, including an evaluation and analysis of non-operative and loss time in harvester technology deployment in the conditions of the Czech Republic, is still missing.

Harvester performance is limited by a number of factors specific both for harvesters and forwarders. However, most authors agree that the basic factors influencing CTL technology performance are vehicle parameters, technological conditions (mainly mensurational parameters of harvested trees) and the human factor – operators (Neruda, Valenta 2003; Nurminen et al. 2006; Dvořák et al. 2012; Aalmo, Baardsen 2015; Erber et al. 2016). Harvester productivity is most significantly influenced by the mean stem volume of harvested trees (Jiroušek et al. 2007; Spinelli et al. 2011; Dvořák et al. 2012; Ghaffariyan et al. 2015; Lazdiņš et al. 2016; Mederski et al. 2016), whereby productivity increases with increasing stem volume and the number of trees processed per unit time decreases as well (Lazdiņš et al. 2016). Specific tree species then primarily affect the speed and quality of delimbing (Dvořák et al. 2012; Erber et al. 2016), with broadleaved, curved and thick-branched trees prolonging the processing time (Lazdiņš et al. 2016) and decreasing performance (Slugeň et al. 2014; Erber et al. 2016) due to the fact that harvesting heads tend to be designed for processing coniferous trees and as such sometimes process broadleaved trees with less quality (Dvořák et al. 2012; Erber et al. 2016). On the other hand, the cutting diameter of the harvesting head does not affect performance very much (Spinelli et al. 2011). Forwarder performance is primarily influenced by forwarding distance and payload, or by parameters of load (Jiroušek et al. 2007; Macků, Dvořák 2010). Larger piles situated close to the technological line shorten the production stage of forwarding, while a large number of produced assortments lowers the productivity of the technology as a whole (Lazdiņš et al. 2016), both from the perspective of harvesters depositing timber into piles and in the course of the load composition by forwarders.

In terms of production conditions, CTL technology performance can be seen as a function of several environmental factors (Aalmo, Baardsen 2015), which include characteristics of the harvested trees, slope inclination, soil structure and characteristics (Aalmo, Baardsen 2015), terrain obstacles, snow cover and ambient temperature (Aalmo, Baardsen 2015; Lazdiņš et al. 2016) and most importantly the human factor (Neruda, Valenta 2003; Nurminen et al. 2006; Purfürst 2009; Aalmo, Baardsen 2015; Hiesl 2015; Lazdiņš et al. 2016). For many of these factors, conclusive and verifiable dependence cannot be established as yet (Jiroušek et al. 2007; Mederski et al. 2016). However, for instance Aalmo and Baardsen (2015) dealt with the issue of terrain obstacles and concluded that they significantly affected performance, while temperature, height of snow cover or slope inclination did not affect performance significantly.

CTL technology performance and productivity are also fundamentally influenced by operators' knowledge, experience and skills (Neruda, Valenta 2003; Dvořák et al. 2012; Hiesl 2015). Despite the fact that the degree of influence exerted by operators on harvester performance cannot be specified so far, all authors agree that operators' experience and skills play a significant role in harvester performance. Purfürst (2009) concluded that operator's impact on machine's performance in similar conditions may amount up to 37%. Similarly, Dvořák et al. (2012) proved that the length of practice influences work performance much more than education attained. Owing to this, long-term and expensive training usually precedes the operators' actual work deployment (Malík, Dvořák 2007; Aalmo, Baardsen 2015). Measurement methodology or the impacts of the human factor on harvester technology performance have not been subjected to comprehensive published studies yet (Hiesl 2015).

When considering the listed factors and technological procedure, the performance of small-power and medium-power harvesters ranges from 2.5 to 15 m^3 of processed wood raw material per hour (Dvořák 2007; Slugeň et al. 2014; Erber et al. 2016; Lazdiņš et al. 2016) and 10 to 40 $m^3 \cdot h^{-1}$ in high-power harvesters, with up to 60 $m^3 \cdot h^{-1}$ in extremely good technological conditions (Jiroušek et al. 2007).

MATERIAL AND METHODS

To determine the mean values of individual unit batch and shift times, we experimentally measured times which harvesters and forwarders of various performance classes reach in normal operating conditions. In order to determine representative values, data from a number of Czech Republic regions (Fig. 1) and different production conditions were obtained. A total of 16 harvesters and 11 forwarders were included in the analysis conducted throughout 2015 and 2016 (Table 1).

Production conditions. The stand character in sites where data were collected met standard work conditions for harvester deployment in the Czech Republic. These stands encompassed mixed coniferous stands to spruce or pine monocultures. Spruce representation ranged from 65 to 100%, pine ranged from 55 to 100%. The most common admixed or interspersed woody species included beech, larch or oak. Stand age ranged from 36 to 139 years. In planned advance felling, the mean height was 15–25 m in spruce and 13–23 m in pine, with the mean tree volume ranging from 0.16 to 0.59 m^3. In planned principal felling, the spruce mean height was 25–33 m and that of pine 22–26 m. Stand density prior to principal planned felling ranged from 7 to 10. Terrain conditions in individual stands were classified according to the "Macků-Simanov-Popelka" terrain classification from 1993, where terrains are grouped into individual terrain types based on their similarity. The main input data included slope inclination, ground bearing capacity and occurrence of terrain obstacles (Simanov et al. 1993). Slope inclination ranged from 0 to 30% and in most cases the terrain was classified as obstacle-free.

Prior to harvesting all stands were duly divided into work fields where technological lines and trees to be felled were marked. When selecting suitable stands, special attention was paid to choosing stands where felling was done using complex CTL technology in standard conditions, where forwarding lines were approximately 20 m apart, their width corresponding to the machinery used but never more than 4 m.

Based on the character of felling, stands were divided into the following categories: planned advance (PA) felling, principal planned (PP) felling and incidental felling. Monitoring of time consumption in stands with incidental felling was deliberately omitted owing to the fact that the specific production conditions and different technological procedures distort the ratio of individual elements of work shift time.

Harvesters and forwarders were divided into performance classes according to a generally recognized classification scheme (Forbrig 2001; Malík, Dvořák 2007; Dvořák et al. 2012), where the engine power is a key parameter. Harvesters

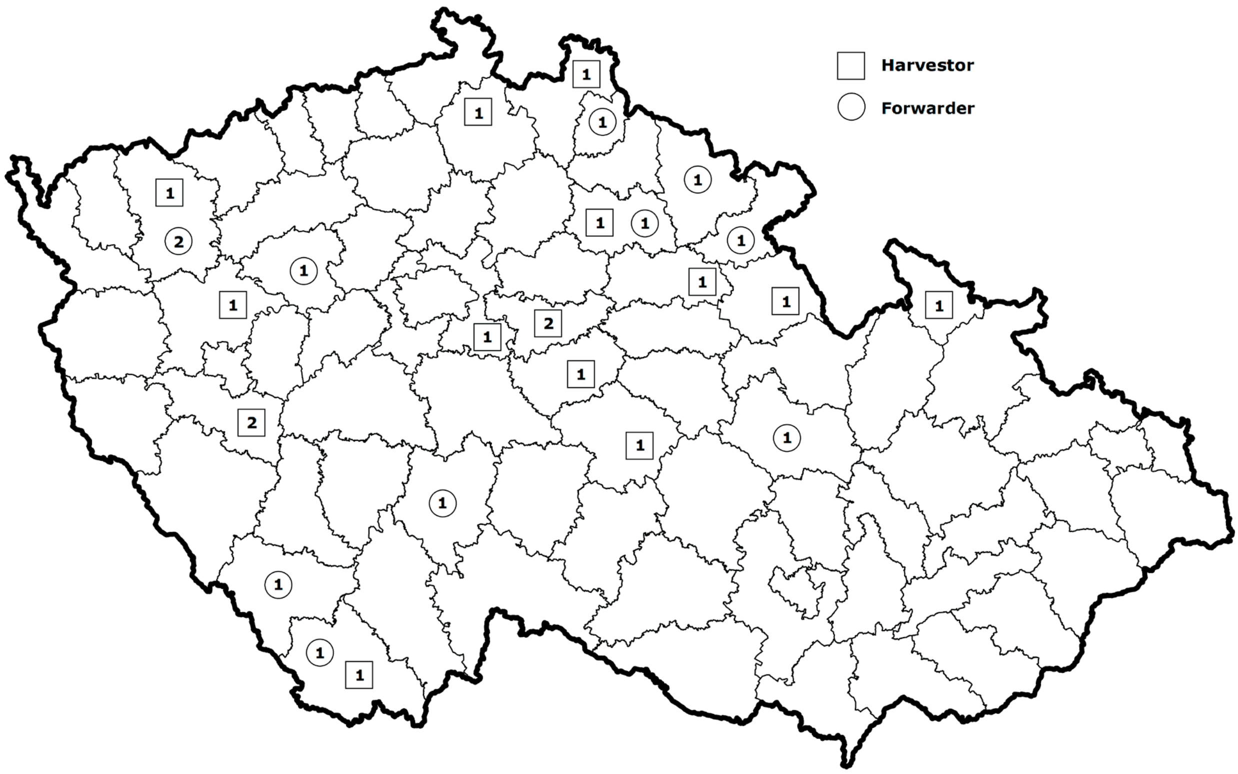

Fig. 1. Sites and number of monitored machines

Table 1. Time consumption in harvesters and forwarders

Monitored machines			Time (min)										
Order number	felling type	manufacturer/type	A_1	B_{101}	B_{102}	C_{103}	C_{104}	C_{105}	T_2	T_E	T_D	other	total
H 1		John Deere 770 D	570	15	0	30	70	0	30	0	10	0	725
H 2		Neuson Ecotec	365	30	10	15	0	0	30	0	30	0	480
H 3		Logset 8H	345	10	30	10	0	20	30	0	20	0	465
H 4	PA	Neuson Ecotec	375	10	10	30	15	0	30	0	10	30	510
H 5		Rottne 5005	600	30	0	5	20	0	30	0	30	0	715
H 6		John Deere 1170 E	666	15	20	0	15	0	30	0	0	6	752
H 7		Neuson Ecotec	198	12	0	10	30	15	30	43	10	0	348
H 8		John Deere 1070 D	570	10	10	10	30	0	30	0	60	0	720
H 9		Ponsse HS 10	340	35	15	30	30	40	30	0	40	10	570
H 10		Timberjack 1270 D	600	30	15	15	15	120	30	0	30	0	855
H 11		Logset 8H	540	40	60	20	0	2	30	0	30	0	722
H 12	PP	John Deere 1270 D	395	5	0	10	40	0	30	0	0	0	480
H 13		Rottne H 14	280	20	15	0	30	0	30	95	10	0	480
H 14		Timberjack 1270 B	600	30	0	30	90	0	30	15	0	0	795
H 15		Gremo 1050 H	535	20	5	5	30	0	30	0	35	0	660
H 16		Timberjack 1270 D	360	80	95	0	120	0	30	0	10	0	695
F 1		Vimek 606	307	17	3	0	60	0	30	49	0	0	466
F 2		Terri 34	300	30	30	10	30	45	30	0	5	0	480
F 3	PA	Loglander LL84	261	10	0	10	6	0	30	0	3	10	330
F 4		Vimek 606 TT	420	20	0	0	0	0	30	10	10	20	510
F 5		Valmet 830	390	0	0	0	30	0	30	0	35	0	485
F 6		Ponsse Wissent	255	10	5	0	0	0	30	150	60	0	510
F 7		John Deere 1110 D	255	0	0	0	0	180	30	0	15	0	480
F 8	PP	Komatsu 840	360	0	0	0	9	0	30	201	0	0	600
F 9		Valmet 840 S2	439	15	5	0	5	60	30	0	5	0	559
F 10		John Deere 1110 D	444	20	0	10	52	0	30	0	4	0	560
F 11		John Deere 1010 E	640	20	0	0	10	0	30	0	30	10	740

H – harvester, F – forwarder, PA – planned advance, PP – principal planned, T_{A1} – production stage performed by harvesters encompassing felling and processing of a tree, T_{B101} – time for preparation and concluding of work, T_{B102} – time for technical servicing of the workplace, T_{C103} – time for work instructions, T_{C104} – time for technical maintenance of the vehicle, T_{C105} – time for repairs, T_2 – time for biological and legally required breaks, T_E – technical and organizational time losses, T_D – personal time losses

are classified into three classes: small – with engine power up to 70 kW, medium – with engine power ranging from 71 to 140 kW and large – with engine power over 140 kW. Forwarders fall into two power classes, small and large, with the engine power of 60 kW representing the limit between them. In vehicles exceeding 60 kW of engine power there is no further classification, as the study draws on the finding that in machines with engine power over 60 kW there is no statistically significant difference in performance and work productivity in relation to engine power (Dvořák et al. 2012).

The study encompassed vehicles from different manufacturers which are commonly deployed in conditions of forest sectors of Central Europe (Table 1). Owing to the fact that there are virtually no small harvesters (engine power up to 70 kW) deployed in the Czech Republic, these machines could not be included in the study. When choosing the harvesters and forwarders, we stressed the importance of their operators, particularly their work experience. The minimum limit was two years of experience with operating a similar means of mechanization, as experienced operators may decrease the influence of inexperienced operators on the total machine work productivity (Neruda, Valenta 2003).

Analysis of work time and the production process. Work shift time consists of unit time, batch time, shift time, time for breaks and loss time. Shift time can be generally divided into necessary time and loss, or unnecessary time (Fig. 2). When preparing time standards, unit, batch and shift times necessary for executing the work process are taken

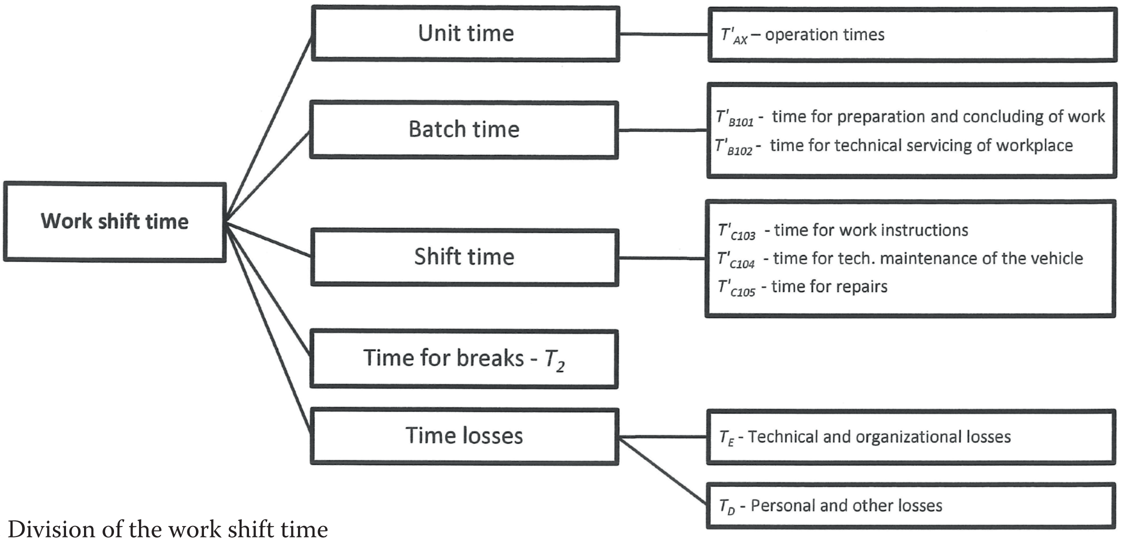

Fig. 2. Division of the work shift time

into account, along with the time for necessary or conditionally necessary breaks (Dvořák et al. 2012). Loss time records are kept separately. The production process consists of unit times, which in turn encompass work operations and segments of work operations specific for harvesters or forwarders.

Times which constitute a work shift were defined and classified according to a standard classification (Dvořák et al. 2012) as follows:

The production stage performed by harvesters encompasses felling and processing of a tree, which is subdivided into work operation segments: time for driving to a new position, time for positioning the harvesting head, time for grasping and felling the tree, time for processing the tree and time for yarding the tree. The production stage performed by the forwarder is referred to as timber forwarding and is subdivided into the following work operations: time for driving the vehicle from roadside to the stand, time for loading, time for driving the load to the roadside and time for unloading at roadside. These work operation and work operation segment times are included in the operation time.

Non-operation batch and shift times are joint for both harvester and forwarder and include the following: time for preparation and concluding of work, time for technical servicing of workplace, time for work instructions, time for technical maintenance of the vehicle, time for repairs, time for biological and legally required breaks, technical and organizational time losses and personal time losses. This study is done with the use of national nomenclature for use in national norms. In terms of international analysis, IUFRO methodology for chronometric studies is used (Björheden, Thompson 2000).

An analysis of operation (unit) time per individual stages of a work operation is important particularly for work performance evaluation. For the purposes of analysing the harvester line work shift utilization, overall operation time was recorded without distinguishing individual segments of work operation.

Measurement and analysis of time consumption. An analysis of a work day, or more precisely of the total shift time, was used to provide a survey of time consumption during a work shift. Measurements and recordings of individual time segments were conducted using continuous chronometry within an accuracy of minutes. A stop-watch was used to measure the time. Shift work time was recorded in notebooks according to the individual types of unit, batch and shift times (in accordance with the methodology described above). Time was always measured started with the operator's arrival or first activity at the workplace and stopped with their departure (unless other activities required for the vehicle's operation in consequent shifts followed up). The data was collected in 2015–2016 to allow us to include the periods of summer and winter harvesting, including the selected specifications.

RESULTS

Over the period of two years a total of 27 work snapshots were taken, monitoring the work shift composition of harvesters and forwarders. The study encompasses 16 snapshots of harvesters and 11 snapshots of forwarders of 22 manufacturers or vehicle types commonly used in the Czech Republic forest sector. Basic data measured in the field are shown in Table 1. Table 2 presents percentage shares of individual types of work shift time.

Table 2. Time consumption share in harvesters and forwarders

Monitored machines			Time (%)										
Order number	felling type	manufacturer/type	A_1	B_{101}	B_{102}	C_{103}	C_{104}	C_{105}	T_2	T_E	T_D	other	total
H 1	PA	John Deere 770 D	78.6	2.1	0.0	4.1	9.7	0.0	4.1	0.0	1.4	0.0	100.0
H 2		Neuson Ecotec	76.0	6.3	2.1	3.1	0.0	0.0	6.3	0.0	6.3	0.0	100.0
H 3		Logset 8H	74.2	2.2	6.5	2.2	0.0	4.3	6.5	0.0	4.3	0.0	100.0
H 4		Neuson Ecotec	73.5	2.0	2.0	5.9	2.9	0.0	5.9	0.0	2.0	5.9	100.0
H 5		Rottne 5005	83.9	4.2	0.0	0.7	2.8	0.0	4.2	0.0	4.2	0.0	100.0
H 6		John Deere 1170 E	88.6	2.0	2.7	0.0	2.0	0.0	4.0	0.0	0.0	0.8	100.0
H 7		Neuson Ecotec	56.9	3.4	0.0	2.9	8.6	4.3	8.6	12.4	2.9	0.0	100.0
H 8	PP	John Deere 1070 D	79.2	1.4	1.4	1.4	4.2	0.0	4.2	0.0	8.3	0.0	100.0
H 9		Ponsse HS 10	59.6	6.1	2.6	5.3	5.3	7.0	5.3	0.0	7.0	1.8	100.0
H 10		Timberjack 1270 D	70.2	3.5	1.8	1.8	1.8	14.0	3.5	0.0	3.5	0.0	100.0
H 11		Logset 8H	74.8	5.5	8.3	2.8	0.0	0.3	4.2	0.0	4.2	0.0	100.0
H 12		John Deere 1270 D	82.3	1.0	0.0	2.1	8.3	0.0	6.3	0.0	0.0	0.0	100.0
H 13		Rottne H 14	58.3	4.2	3.1	0.0	6.3	0.0	6.3	19.8	2.1	0.0	100.0
H 14		Timberjack 1270 B	75.5	3.8	0.0	3.8	11.3	0.0	3.8	1.9	0.0	0.0	100.0
H 15		Gremo 1050 H	81.1	3.0	0.8	0.8	4.5	0.0	4.5	0.0	5.3	0.0	100.0
H 16		Timberjack 1270 D	51.8	11.5	13.7	0.0	17.3	0.0	4.3	0.0	1.4	0.0	100.0
F 1	PA	Vimek 606	65.9	3.6	0.6	0.0	12.9	0.0	6.4	10.5	0.0	0.0	100.0
F 2		Terri 34	62.5	6.3	6.3	2.1	6.3	9.4	6.3	0.0	1.0	0.0	100.0
F 3		Loglander LL84	79.1	3.0	0.0	3.0	1.8	0.0	9.1	0.0	0.9	3.0	100.0
F 4		Vimek 606 TT	82.4	3.9	0.0	0.0	0.0	0.0	5.9	2.0	2.0	3.9	100.0
F 5		Valmet 830	80.4	0.0	0.0	0.0	6.2	0.0	6.2	0.0	7.2	0.0	100.0
F 6	PP	Ponsse Wissent	50.0	2.0	1.0	0.0	0.0	0.0	5.9	29.4	11.8	0.0	100.0
F 7		John Deere 1110 D	53.1	0.0	0.0	0.0	0.0	37.5	6.3	0.0	3.1	0.0	100.0
F 8		Komatsu 840	60.0	0.0	0.0	0.0	1.5	0.0	5.0	33.5	0.0	0.0	100.0
F 9		Valmet 840 S2	78.5	2.7	0.9	0.0	0.9	10.7	5.4	0.0	0.9	0.0	100.0
F 10		John Deere 1110 D	79.3	3.6	0.0	1.8	9.3	0.0	5.4	0.0	0.7	0.0	100.0
F 11		John Deere 1010 E	86.5	2.7	0.0	0.0	1.4	0.0	4.1	0.0	4.1	1.4	100.0

H – harvester, F – forwarder, PA – planned advance, PP – principal planned, T_{A1} – production stage performed by harvesters encompassing felling and processing of a tree, T_{B101} – time for preparation and concluding of work, T_{B102} – time for technical servicing of the workplace, T_{C103} – time for work instructions, T_{C104} – time for technical maintenance of the vehicle, T_{C105} – time for repairs, T_2 – time for biological and legally required breaks, T_E – technical and organizational time losses, T_D – personal time losses

By separating time losses, i.e. technical and organizational losses and personal losses and others, we obtained a summary of times necessary for performing a work operation – the so-called normative times (Table 3).

The collected data reveal that the average harvester working time is 623 min and that of forwarders is 520 min. Out of the total working time, 73.6% (459 min) is the average operation time in harvesters and 71.2% (370 min) in forwarders.

Following the work shift analysis of work snapshots Table 4 was compiled, containing average absolute and percentage values corresponding to unit, batch and shift times in harvesters and forwarders in relation to the type of felling.

The data collected were statistically processed using the *t*-test. In the course of statistical testing all variables were considered independent samples.

The average work shift time is 623 and 520 min in harvesters and forwarders, respectively. It follows that within one operation unit harvesters would face downtime. If the harvester and the forwarder worked within a single unit, their work times should be close to one value. However, this ideal situation is virtually impossible to achieve in practice, therefore harvesters usually work in advance and create a stock of removals for forwarders to deal with. When concluding work at a given workplace, the harvester moves straight to a new workplace.

A statistically significant difference (significance level $\alpha = 0.05$) was found between total shift times in PA and PP felling (Table 5). Since no statistically significant difference was validated between unit times in this case, it is evident that the difference was caused by other work shift times. This may be caused by random and unexpected events occur-

Table 3. Normative times of harvester and forwarder work shifts

Monitored machines			Time (min)								
Order number	felling type	manufacturer/type	A_1	B_{101}	B_{102}	C_{103}	C_{104}	C_{105}	T_2	other	total
H 1	PA	John Deere 770 D	570	15	0	30	70	0	30	0	715
H 2		Neuson Ecotec	365	30	10	15	0	0	30	0	450
H 3		Logset 8H	345	10	30	10	0	20	30	0	445
H 4		Neuson Ecotec	375	10	10	30	15	0	30	30	500
H 5		Rottne 5005	600	30	0	5	20	0	30	0	685
H 6		John Deere 1170 E	666	15	20	0	15	0	30	6	752
H 7		Neuson Ecotec	198	12	0	10	30	15	30	0	295
H 8	PP	John Deere 1070 D	570	10	10	10	30	0	30	0	660
H 9		Ponsse HS 10	340	35	15	30	30	40	30	10	530
H 10		Timberjack 1270 D	600	30	15	15	15	120	30	0	825
H 11		Logset 8H	540	40	60	20	0	2	30	0	692
H 12		John Deere 1270 D	395	5	0	10	40	0	30	0	480
H 13		Rottne H 14	280	20	15	0	30	0	30	0	375
H 14		Timberjack 1270 B	600	30	0	30	90	0	30	0	780
H 15		Gremo 1050 H	535	20	5	5	30	0	30	0	625
H 16		Timberjack 1270 D	360	80	95	0	120	0	30	0	685
F 1	PA	Vimek 606	307	17	3	0	60	0	30	0	417
F 2		Terri 34	300	30	30	10	30	45	30	0	475
F 3		Loglander LL84	261	10	0	10	6	0	30	10	327
F 4		Vimek 606 TT	420	20	0	0	0	0	30	20	490
F 5		Valmet 830	390	0	0	0	30	0	30	0	450
F 6	PP	Ponsse Wissent	255	10	5	0	0	0	30	0	300
F 7		John Deere 1110 D	255	0	0	0	0	180	30	0	465
F 8		Komatsu 840	360	0	0	0	9	0	30	0	399
F 9		Valmet 840 S2	439	15	5	0	5	60	30	0	554
F 10		John Deere 1110 D	444	20	0	10	52	0	30	0	556
F 11		John Deere 1010E	640	20	0	0	10	0	30	10	710

H – harvester, F – forwarder, PA – planned advance, PP – principal planned, T_{A1} – production stage performed by harvesters encompassing felling and processing of a tree, T_{B101} – time for preparation and concluding of work, T_{B102} – time for technical servicing of the workplace, T_{C103} – time for work instructions, T_{C104} – time for technical maintenance of the vehicle, T_{C105} – time for repairs, T_2 – time for biological and legally required breaks

Table 4. Average time consumption in relation to the type of felling (PA – planned advance, PP – principal planned)

Type of time	Harvesters				Forwarders			
	PA		PP		PA		PP	
	min	%	min	%	min	%	min	%
Work operation (A_1)	446	78.2	469	70.6	336	73.8	399	69.2
Preparation and concluding of work (B_{101})	17	3.0	30	4.5	15	3.3	11	1.9
Technical servicing of workplace (B_{102})	10	1.8	24	3.6	7	1.5	2	0.3
Work instructions (C_{103})	14	2.5	13	2.0	4	0.9	2	0.3
Vehicle maintenance (C_{104})	21	3.7	43	6.5	25	5.5	13	2.3
Repairs (C_{105})	5	0.9	18	2.7	9	2.0	40	6.9
Biological and legally required breaks (T_2)	30	5.3	30	4.5	30	6.6	30	5.2
Technical and organizational losses (T_E)	6	1.1	12	1.8	12	2.6	59	10.2
Personal losses (T_D)	16	2.8	24	3.6	11	2.4	19	3.3
Other	5	0.9	1	0.2	6	1.3	2	0.3
Total	570	100	664	100	455	100	577	100
Work shift utilization (%)	95.3		94.4		93.6		86.1	

Table 5. Comparison of unit time and shift time in forwarders in relation to the type of felling (PA – planned advance, PP – principal planned)

Time	Mean (min)		*t*	*df*	*P*	No. of measurements		Standard deviation (min)	
	PA	PP				PA	PP	PA	PP
Unit	335.6	398.8	–0.895	9	0.39	5	6	66.583	144.706
Total	454.2	574.8	–2.403	9	0.04	5	6	71.226	91.193

t – value of test statistic, *df* – degree of freedom, *P* – probability

Table 6. Comparison of unit time and shift time in harvesters in relation to the type of felling (PA – planned advance, PP – principal planned)

Time	Mean (min)		*t*	*df*	*P*	No. of measurements		Standard deviation (min)	
	PA	PP				PA	PP	PA	PP
Unit	445.6	468.9	–0.319	14	0.75	7	9	168.719	124.318
Total	570.7	664.1	–1.292	14	0.21	7	9	158.208	131.181

t – value of test statistic, *df* – degree of freedom, *P* – probability

ring throughout the monitored work shifts. In a smaller data sample from the monitored machines random occurrence of less common situations then plays a much more important role. In the future the difference would probably gradually disappear if calculated from a higher number of machines and shifts. A statistically significant difference between PA and PP shift times (significance level α = 0.05) in harvesters was not validated (Table 6).

Table 7 reveals that the difference in total work shift time between harvesters and forwarders at the significance level (α = 0.05) is statistically significant. Upon revealing a statistically significant difference it needs to be verified whether both machines in the operation unit operate at 100%. However, in normal operation and in conditions of the forest sector, the harvester unit hardly ever works at maximum performance owing to the highly variable working conditions which primarily depend on the stand character, natural conditions and other specific production conditions.

In forest practice, the time difference and downtime caused by different operation times of harvesters vs. forwarders due to different working conditions are usually minimized through the deployment of harvesters ahead of forwarders. This fact also influences the results obtained, as harvester and forwarder work snapshots were taken separately, not within a single harvester unit.

Harvester operation time is primarily conditioned by the mean stem volume of logged trees. However, the time consumption in relation to the mean stem volume of logged trees was not analysed due to the small size of sample. Forwarder operation time is also conditioned by mean stem volume but it is primarily influenced by the distance between workplace and roadside, i.e. the forwarding distance. This dependence was not subjected to analysis under the presented study.

DISCUSSION AND CONCLUSIONS

Most contemporary studies focusing on harvester performance analyse the operation time (Jiroušek et al. 2007; Erber et al. 2016; Lazdiņš et al. 2016; Mederski et al. 2016), which however represents only one type of times which constitute the work shift of a harvester or forwarder operator. The results of such studies present limits of technical efficiency which a given machine can reach in more or less optimum conditions, i.e. the maximum potential of the machine (Aalmo, Baardsen 2015). However, the long-term perspective and normal operating conditions in the forest sector need to take into consideration other times necessary for the operation of logging and hauling machinery and for the complex delivery of work. This allows us

Table 7. Comparison of total shift time in a harvester line in relation to logging and hauling machinery

	Average (min)		*t*	*df*	*P*	No. of measurements		Standard deviation (min)	
	harvester	forwarder				harvester	forwarder	PA	PP
Total time	623.3	520.0	2.025	25	0.05	16	11	146.559	100.778

t – value of test statistic, *df* – degree of freedom, *P* – probability to determine vehicle performance per unit of time worked in the long-term horizon. When determining technical performance, non-operative time or downtime ranges between 3 and 5% in most studies. However, the ratio of individual non-operative times is conditioned by a number of variables, most importantly the volume of harvested trees (Jiroušek et al. 2007; Spinelli et al. 2011; Dvořák et al. 2012; Ghaffariyan et al. 2015; Lazdiņš et al. 2016; Mederski et al. 2016) and forwarding distance in forwarders (Jiroušek et al. 2007; Macků, Dvořák 2010; Lazdiņš et al. 2016). To a lesser degree, CTL technology performance is influenced by a number of other factors, e.g. slope inclination, terrain obstacles, snow depth or temperature. Work performance can be greatly influenced by operator's experience and skills (Nurminen et al. 2006; Jiroušek et al. 2007; Spinelli et al. 2011; Dvořák et al. 2012; Aalmo, Baardsen 2015; Lazdiņš et al. 2016). However, their impact on resulting performance cannot be determined accurately as yet due to difficulties in quantifying this factor (Jiroušek et al. 2007; Hiesl 2015; Mederski et al. 2016).

Generally, the value of 0.75 (75% of shift time) is considered a relevant coefficient expressing the ratio of operation time within every hour of a shift (Glöde, Sikström 2001; Jiroušek et al. 2007), which corresponds to the findings of our research where the operation time ratio ranges between 70.6 and 78.2%. Dvořák (2007) drew the same conclusion, quoting 72.6% of operation time in harvesters, similarly to Dvořák and Keivan Behjou (2011), who determined the operation time ratio of approximately 73% in forwarders. Olivera and Visser (2016) specified 71% of operation time as well. When determining the time consumption, Szewczyk et al. (2016) further distinguished types of felling depending on the stand age and drew the conclusion that the operation time ratio ranged between 41 and 53%, observing that the highest operation time ratio can be found in clear felling. They accounted for the relatively high percentage of non-operation time by high time consumption necessary for technological preparation due to relatively complex production conditions. On average, non-operation time represents approximately 30%. However, this figure may range between 20 and 70% of the work shift time (Spinelli, Visser 2008).

Slugeň et al. (2014) also studied harvester performance in purely broadleaved thinned stands, where operation time ranged between 65 and 84%, with repairs usually taking up a big share of non-operation time (5–25% of total shift time) (Dvořák, Keivan Behjou 2011; Slugeň et al. 2014; Olivera, Visser 2016; Szewczyk et al. 2016). It turns out, however, that the time for repairs increases with increasing machine age or with working conditions. Our study arrived at the same conclusion, revealing that older vehicles suffered more frequent, more serious and more time-consuming breakdowns, which means that one cannot be fully in control of the time consumption for repairs and maintenance. On the other hand, the time for preparation, maintenance and rehabilitation of the workplace primarily depends on operators' skills and thoroughness. The time for biological and legally required breaks is specified by law, yet the breaks are often cut short or even left out because the operator combined the break time with different work activities, which is unacceptable under Act No. 262/2006 Coll. (Labour Code) and related legal regulations (Dvořák 2007; Dvořák et al. 2012). It follows that work performance or efficiency can be improved only through optimization or reduction of technical and organizational time losses, personal and other losses. This can be achieved mainly through optimized work organization in the form of timely and good-quality preparation of workplaces, vehicle transport logistics and moving the machines between individual workplaces. The share of non-operative time in our study ranged between 21.8 and 29.4%, which corresponds to findings of other authors and represents room for increasing the ratio of operation time and better utilization of work shift. However, even if personal losses are unnecessary from the perspective of technology performance, they are not often seen as unnecessary by operators themselves (Dvořák et al. 2012) and as such are highly problematic to eliminate.

Obviously, another option for improving performance which is applied as well is to increase vehicle performance. However, owing to the fact that modern logging and hauling machinery is very well constructed and highly sophisticated through long development (Gerasimov et al. 2013), it is necessary to apply more sophisticated methods of their performance enhancement but the technical performance improves more slowly. Yet, compared with studies conducted in the 1990s work performance has increased by 12–35% (Mederski et al. 2016).

References

Aalmo G.O., Baardsen S. (2015): Environmental factors affecting technical efficiency in Norwegian steep terrain logging crews: A stochastic frontier analysis. Journal of Forest Research, 20: 18–23.

Björheden R., Thompson M.A. (2000): An international nomenclature for forest work study. In: Field D.B. (ed.): Proceedings of the 20th IUFRO World Congress – Caring for the Forest: Research in a Changing World, Tampere, Aug 6–12, 1995: 190–215.

Dvořák J. (2007): Performance of tracked harvesters of I class in spruce stands. Lesnícky časopis – Forestry Journal, 54: 47–56.

Dvořák J., Keivan Behjou F. (2011): Performance standards of medium- and high-power forwarders. In: Kanzian C. (ed.): Proceedings of the 44th International Symposium on Forestry Mechanisation: Pushing the Boundaries with Research and Innovation in Forest Engineering, Graz, Oct 9–13, 2011: 1–12.

Dvořák J., Bystrický R., Hošková P., Hrib M., Jarkovská M., Kováč J., Krilek J., Natov P., Natovová L. (2012): The Use of Harvester Technology in Production Forests. Kostelec nad Černými lesy, Lesnická práce, s.r.o.: 156.

Erber G., Holzleitner F., Kastner M., Stampfer K. (2016): Effect of multi-tree handling and tree-size on harvester performance in small-diameter hardwood thinnings. Silva Fennica, 50: 1428.

Forbrig A. (2001): Zur technischen Arbeitsproduktivität von Kranvollernter. Forstechnische Information, 53: 22–25.

Gerasimov Y., Sokolov A., Syunev V. (2013): Development trends and future prospects of cut-to-length machinery. Advanced Materials Research, 705: 468–473.

Ghaffariyan M.R., Apolit R., Kuehmaier M. (2015): Analysis and control of fuel consumption rates of harvesting systems: A review of international studies. Industry Bulletin, 15: 1–4.

Glöde D., Sikström U. (2001): Two felling methods in final cutting of shelterwood, singlegrip harwester produktivity and damage to the regeneration. Silva Fennica, 35: 71–83.

Hiesl P. (2015): Forest harvesting productivity and cost in Maine: New tools and processes. [Ph.D. Thesis.], Orono, University of Maine: 143.

Jiroušek R., Klvač R., Skoupý A. (2007): Productivity and costs of the mechanised cut-to-length wood harvesting system in clear-felling operations. Journal of Forest Science, 53: 476–482.

Lazdiņš A., Prindulis U., Kalēja S., Daugaviete M., Zimelis A. (2016): Productivity of Vimek 404 T5 harvester and Vimek 610 forwarder in early thinning. Agronomy Research, 14: 475–484.

Macků J., Dvořák J. (2010): Time expenditure analysis of cut-to-length harvesters in incidential fellings compared with production efficiency. In: Kanzian C. (ed.): Proceedings of the 43th International Symposium on Forestry Mechanisation: Forest Engineering: Meeting the Needs of the Society and the Environment, Padova, July 11–14, 2010: 1–7.

Malík V., Dvořák J. (2007): Harvestorové technologie a vliv na lesní porosty. Kostelec nad Černými lesy, Lesnická práce, s.r.o.: 84.

Mederski P.S., Bembenek M., Karaszewski Z., Łacka A., Szczepańska-Álvarez A., Rosińska M. (2016): Estimating and modelling harvester productivity in pine stands of different ages, densities and thinning intensities. Croatian Journal of Forest Engineering, 37: 27–36.

Nakagawa M., Hamatsu J., Saitou T., Ishida H. (2007): Effect of tree size on productivity and time required for work elements in selective thinning by a harvester. International Journal of Forest Engineering, 18: 24–28.

Neruda J., Valenta J. (2003): Factors of the efficiency of harvesters and forwarders in logging. In: Visser R. (ed.): Austro2003: High Tech Forest Operations for Mountainous Terrain, Schlaegl, Oct 5–9, 2003: 1–11.

Nurminen T., Korpunen H., Uusitalo J. (2006): Time consumption analysis of the mechanized cut-to-length harvesting system. Silva Fennica, 40: 335–363.

Olivera A., Visser R. (2016): Using the harvester on-board computer capability to move towards precision forestry. New Zealand Journal of Forestry, 60: 3–7.

Palander T., Ovaskainen H., Tikkanen L. (2012): An adaptive work study method for identifying the human factors that influence the performance of a human-machine system. Forest Science, 58: 377–389.

Purfürst F.T. (2009): Der Einfluss des Menschen auf die Leistung von Harvestersystemen. [Ph.D. Thesis.] Dresden, Institut für Forstnutzung und Forsttechnik: 307.

Simanov V., Macků J., Popelka J. (1993): Nový návrh terénní klasifikace a technologické typizace. Lesnictví – Forestry, 39: 422–428.

Slugeň J., Peniaško P., Messingerová V., Janovský M. (2014): Productivity of a John Deere harvester unit in deciduous stands. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 62: 231–238.

Spinelli R., Visser R. (2008): Analyzing and estimating delays in harvester operations. International Journal of Forest Engineering, 19: 36–41.

Spinelli R., Magagnotti N., Hartsough B. (2011): Productivity norms for harvesters and processors used in Italy. In: Kanzian C. (ed.): Proceedings of the 44th International Symposium on Forestry Mechanisation: Pushing the Boundaries with Research and Innovation in Forest Engineering, Graz, Oct 9–13, 2011: 1–8.

Szewczyk G., Sowa J.M., Dvořák J., Kamiński K., Kulak D., Stańczykiewicz A. (2016): Analysis of accuracy of evaluating the structure of a harvester operator's workday by work sampling. Croatian Journal of Forest Engineering, 37: 251–259.

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