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OPERATION TIME CONSUMPTION OF HIGH-POWERED HARVESTER IN SALVAGE FELLING

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ABSTRACT

In the Czech Republic, harvester technologies represent the second most-frequently used technology. Demand for high efficiency in this type of technology is conditioned by the need to cover acquisition and operation costs. The aim of this study is to monitor *operation time* of a high-powered Ponsse Ergo harvester. Felling process in the course of salvage felling was analyzed with the help of continuous chronometry. The analysis was conducted for harvesting of spruce ranging from 0.05–2.00 m^3/stem. Operation time consumption for the processing of a tree ranges from 62 s to 171 s in relation to the respective tree volume, which represents 0.02–0.24 h/m^3 of operation time.

Key words: harvester, operation time, productivity

INTRODUCTION

The intensity of assortment harvesting using harvester technologies has been on the increase in the Czech Republic. At present, the Czech forest management operates an estimated 500 harvesters and over 300 forwarders. This technology ranks second after motor-manual cutting, as it accounts for approximately 29 % of planned annual cut in the Czech Republic [13]. It is estimated that the deployment of logging and hauling machinery will continue to increase and that it will copy Western Europe where the ratio of assortment harvesting accounts for up to 60 % (e.g. Germany). The highest number of deployed harvesters and forwarders is confirmed in Scandinavian countries with approximately 90 % ratio of harvester technology use [12,20].

Harvester machinery is deployed for a number of reasons. These encompass savings in labour costs, better ergonomics and work hygiene, immediate reaction to customer demand, minimum contamination of harvested timber and a high standard in work cleanness in the course of logging and hauling. On the other hand, the downsides include high acquisition costs, demanding work organization, long-term and costly personnel training as well as problems with securing qualified operators.

Harvester performance is monitored with regard to production factors which include the volume of harvested trees, harvesting intensity and other [4,6,9,10,16,17,18]. At present, manpower, i.e. harvester operators whose performance is conditioned by training and experience, is increasingly seen as a key factor in the achieved productivity [1,3,5,11,15].

The aim of this paper was to assess harvester productivity and check the quality of salvage felling conducted at the Dobříš Forest Enterprise which is managed by Forests of the Czech Republic, State Enterprise.

MATERIAL AND METHODS

The research focuses on a detailed analysis of harvester work snapshots in salvage felling. Conducted measurements encompass productivity observation and work process in relation to time units. The monitored vehicle is Ponsse Ergo high-powered harvester.

Production Conditions

The preliminary time study draws on measurements of 108.5 hours of Ponsse Ergo harvester work time. Independent operation time was measured in 631 processed trees of a total volume 620.49 m^3. The trees were distributed among 15 production units. The total summary of felled trees, processed timber volume and mean timber volume is shown in Table 1. Harvesting was conducted in terrain conditions specified by terrain type 11 according to Macků-Simanov-Popelka terrain classification (i.e. terrain slope up to 10 %, good ground strength and terrain free of obstacles). Respective forest stands were properly divided into work fields of 20–25 m in width with forwarding lines of up to 3 m in width running through their centres.

Table 1. Number and volume of felled trees from the analytical sample measured by chronometry

Processed tree species		Number of processed trees	Volume of processed trees	Mean tree volume	Ratio
		(segments)	(m^3)	(m^3/stem)	(%)
spruce	normal tree	119	139.99	1.17	22.6
	lodged tree	25	30.62	1.22	4.9
	windfall	186	209.90	1.13	33.8
	broken tree	150	97.25	0.65	15.7
pine	normal tree	75	67.49	0.90	10.9
	windfall	46	51.75	1.15	8.3
	broken tree	30	23.49	0.78	3.8
	Total	**631**	**620.49**		

Work Process Time

Together with time analysis, an analysis of the logging and hauling work process was conducted. The production process starts with the harvester entering its work position and is concluded with stem assortment. The production process is divided into consequent actions or work segments which are all encompassed in the given work operation – *harvesting and processing of a tree with a harvester* – which commences with the vehicle driving to its work position and is concluded with processing of every tree marked for felling.

1. *vehicle travel to a new position* (t'_{A121}) – this work operation segment commences when the vehicle starts moving after concluding tree assortment and finishes by its stopping in front of a tree which the operator is planning to process.
2. *approach of the felling head* (t'_{A122}) – measurement of this work operation segment starts after the vehicle's travel to the felled tree has been finished. This is true also in cases when the hydraulic crane is operated simultaneously during the travel. The work operation is concluded by clamping the knives and embracing the stem by the felling head.
3. *felling the tree* (t'_{A123}) – the span of this work operation segment is registered between clasping of the tree by the felling head on the hydraulic crane (grasping of the feed rollers), cutting the tree and its completed fall or placing on the ground by the hydraulic crane.
4. *stem processing* (t'_{A124}) – this work operation segment starts with gripping the felled tree by the felling head or placing the felled tree on the ground upon not releasing it from the head. The segment is completed when the tree tip, which cannot be processed into any other type of assortment, is cut off from the stem and the vehicle moves to another standing tree. At the point the work cycle is completed and starts anew. Stem processing includes continuous debranching and stem grading.

The above listed stages represent t'_{A1} as the measured time of segment work necessary for the processing a single tree into relevant assortments by a harvester. This time is then divided into individual work operation segments.

Work process may also encompass stages of a work operation which are not conditioned by the continuous production process. These include the following:

tree transfer (t'_{A125}) – this work operation segment is conducted in cases when consequent processing of a tree cannot be conducted in the same position of the vehicle which conducted the felling. The vehicle transfers the tree to the forwarding line where it is processed by the above mentioned work operations. The work operation segment – tree transfer – commences with the fall of the entire tree or with placing the tree, which has not been released from the felling head, on the ground by the hydraulic crane. This work operation segment is completed when the tree is transferred to the forwarding line or when the handling of the tree at the forwarding line has been completed and another work operation has commenced.

The work operation segments do not need to be repeated in regular cycles as listed above. The operator may fell several trees at a time which are then individually processed or debranched and sorted. Work operation thus can be divided into two classes:

1) continuous:

$$t'_{AK} = t'_{A121} + t'_{A122} + t'_{A123} + t'_{A124} \quad (1)$$

2) interrupted:

$$t'_{AP} = t'_{A121} + t'_{A122} + t'_{A123} + t'_{A125} + t'_{A122} + t'_{A124} \quad (2)$$

In the course of the production process, other work operation segments take place. These are concurrent with some of the previous operations and thus do not allow or require individual measurements of necessary time. Such work operations include *measurement of tree length and diameter*, *volume measurement* of the processed stems and produced assortments, as well as *skidding of the tree* from the stand to the forwarding line. They are included in time necessary for stem processing, as they are conducted concurrently with these work operation segments.

In order to get an informed overview of total time consumption during a work shift, a work day or work shift analysis must be conducted. For the purposes of the analysis, time consumption is measured throughout the work shift, from the start of the operator's first activity of the given shift until his departure from the work place not followed with any other activity connected to securing necessary provisions for the vehicle's operation in the following shifts. Measurements and analyses provided values of time consumed not only during the work process itself but other non-operative times as well, i.e. the time necessary for *preparation and concluding of work* (T'_{C111}), *work instructions* (T'_{C112}), *technical servicing of the work place* (T'_{C113}), *technical maintenance of the machine* (T'_{C114}), *time for repairs* (T'_{C115}), *biological and legally required breaks* (T'_2), *other necessary breaks* (T'_Z) and *other unforeseeable situations* (T'_{C116}).

RESULTS

Research measurements focused on the felling and processing of 631 trees of a total volume 620.49 m^3, of which absolute majority (62%) were processed in continuous work operations and 38% were processed in interrupted work operations. The work operation time was divided into five work segments (see Chapter 2.2.).

When analyzing harvester productivity, one must take into account species determination of a given processed tree or the definition and quantity of the produced assortments. Operation time increases with the number of cross-cuts in the course of tree processing (Table 2a, b). The number of cross-cuts ranged from 3 to 14. However, the category of cross-cuts does not include the cuts necessary for felling the tree. The difference between the number of assortments and cross-cuts (2–4 cuts) is primarily due to shortening tree tips over the forwarding line which the harvesters consequently drive over.

Table 2a. Consumption of time necessary for stem grading upon its processing, with respect to the number of produced assortments

		Number of cross-cuts					
		3	4	5	6	7	8
Time interval for processing the tree	(s)	[46–69]	[85–163]	[48–210]	[40–244]	[55–344]	[54–285]
Mean tree volume	(m^3/stem)	0.36	0.44	0.53	0.50	0.87	0.94
Ratio in relation to the number of measured trees	(%)	2.2	3.6	3.6	7.2	15.1	18.0

Table 2b. Consumption of time necessary for stem grading upon its processing, with respect to the number of produced assortments

		Number of cross-cuts					
		9	10	11	12	13	14
Time interval for processing the tree	(s)	[15–284]	[54–257]	[83–271]	[179–249]	[100]	[131–236]
Mean tree volume	(m^3/stem)	0.92	1.03	1.25	1.40	0.52	1.72
Ratio in relation to the number of measured trees	(%)	2.2	3.6	3.6	7.2	15.1	18.0

Upon deploying high-powered vehicles in spruce forest stands of tree volume between 0.12–2.05 m^3/stem (this interval encompasses 95% of all harvested trees of the given volume), round timber accounts for the highest production share (70.2%), followed by the production of pulpwood (28.7%), while the lowest share falls to fuel wood (1.1%).

Analysis of time consumption in relation to the tree character prior to its processing

Analysis of variance monitors the statistical significance of differences between mean values of randomly selected operation time consumption which is necessary for processing of trees in relation to the character of their position on the felling area:

– normal, i.e. undamaged trees,
– windfalls,
– broken trees,
– lodged trees.

For analytical purposes, spruce was selected because it predominates in experimental measurements and accounts for 77% of the processed tree volume. Calculations of the STATISTIKA 8.0 software, which are summarized in Table 3, reveal differences of significance level $\alpha = 0.05$ in operation time consumption between operation times for the processing of trees of different position prior to their processing, i.e. between a minimum of two mean values of time out of four registered data sets. Identification of unambiguously different pairs of mean operation time consumption in relation to the tree position needs to be conducted with the help of a more detailed evaluation of the variance analysis results.

Table 3. Analysis of variance for simple grading

Factor	TS [1)]	Degrees of freedom	*F*-value	*p*-value
Between mean values of grades	44793.2	3	3.69	**0.0142**
Within grades	420348.0	104		
Total	465141.0	107		

[1)] *Total of square deviations*

A detailed evaluation of the variance analysis with the help of *Fisher's method* is shown in Table 4. Statistically significant difference of 5% significance level in the table is confirmed among individual classes in cases when crosses between rows do not overlap. However, should they be positioned above each other, the statistical significance of differences between individual classes cannot be confirmed for 95% reliability level. The results thus unambiguously reveal a statistically significant difference between mean segment time consumption in broken and lodged trees. Statistical significance between consumption of time necessary for processing normal trees and windfalls, windfalls and broken trees as well as windfalls and lodged trees has not been confirmed.

Table. 4 Detailed evaluation through Fisher's method, mean time consumption in relation to tree positioning prior to processing

Tree positioning	Number of measurements	Mean consumption of segment time	Group difference
	(trees)	(s)	
(1) normal tree	271	162	X
(2) windfall	244	141	XX
(3) broken tree	150	113	X
(4) lodged tree	25	188	X
Yield difference (d_{sk}) between mean values of rows :			
(1) vs. (2)	20.99 (limit +/- 31.41)		
(1) vs. (3)	* 48.64 (limit +/- 34.53)		
(1) vs. (4)	-26.66 (limit +/- 61.98)		
(2) vs. (3)	27.65 (limit +/- 29.22)		
(2) vs. (4)	-47.65 (limit +/- 59.19)		
(3) vs. (4)	* -75.30 (limit +/- 60.90)		

Analysis of work operation segments

With harvesters, the biggest time share of a work operation falls to the segment of tree processing (t_{124}), whose length with regard to the processed raw material in salvage felling ranges from 60–79 s. In spruce, average share of this time in analyzed stands accounts for 51% (74 s). Time necessary for vehicle travel into a new position accounts for 31% (43 s); approach of the harvesting head accounts for 13% (19 s) and time necessary for felling the tree represents 4% (5 s) of the total time for work operation. In spruce, average time for transferring a tree accounts for only 1 % of the work operation time. Its almost zero value is affected by the high quality of work organization. The ratio of time consumption in relation to work operation segments is summarized in Table 5 and is analyzed in the following sub-chapters.

Table 5. Mean ratio of work operation segments in relation to the character of the processed spruce's positioning

Work operation segment	Normal tree	Windfall	Broken tree	Lodged tree
	(%) / (s)			
t_{121} [1)]	30 / 48	30 / 43	29 / 33	49 / 93
t_{122} [2)]	11 / 18	13 / 18	17 / 19	10 / 19
t_{123} [3)]	10 / 17	0 / 0	1 / 1	8 / 15
t_{124} [4)]	49 / 79	56 / 79	53 / 60	32 / 61
t_{125} [5)]	0 / 0	1 / 1	0 / 0	0 / 0
Total time (s)	**162**	**141**	**113**	**188**

[1)] Time necessary for vehicle travel into a new position, [2)] time for pulling up the felling head, [3)] time for felling the tree, [4)] time for processing the tree, [5)] time for transferring the tree.

Time necessary for vehicle travel into a new position (t_{A121})

The Ponsse Ergo high-powered harvester was deployed for processing spruce of volume ranging from 0.07 to 2.20 m^3/stem. A total of 505 felled and processed spruces were measured and analyzed.

For practical and operational reasons, time consumption was analyzed in relation to the volume of harvested trees. Harvested stem volume (h) is a key factor which conditions performance standards for harvesting activities. Figure 1 shows a marked change in time necessary for vehicle travel into a new position (t_{A121}) in relation to stem volume. Stem volume can thus be considered an indirect independent variable which varies in relation to tree spacing which in turn affects distance and time necessary for vehicle travel. [14] mentions independence of this time on tree species. However, mensurational characteristics produce evidence, in accordance with Decree No. 84/1996 on Forest Management Planning [19], that the numbers of different species per hectare vary upon constant volume and yield class. Our analysis therefore retained the dependence on volume and tree species in order to determine the total time necessary for a work operation.

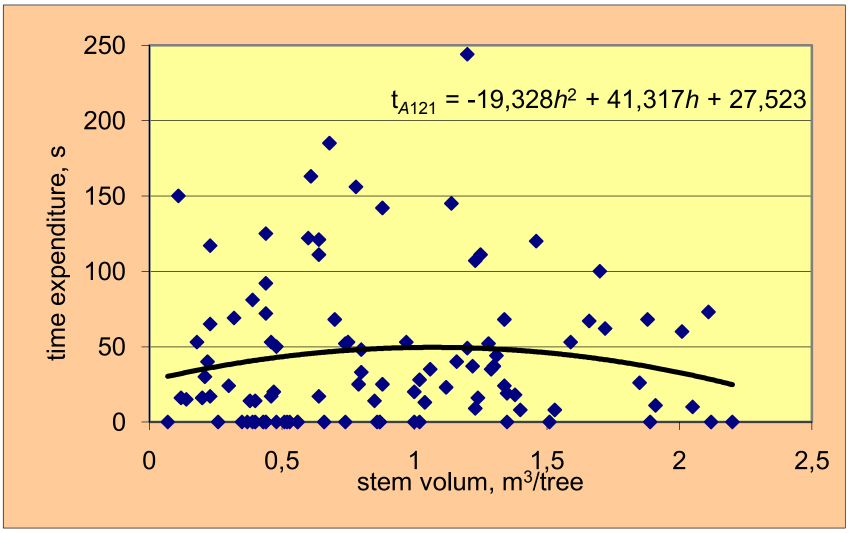

Fig. 1. Time necessary for vehicle travel into a new position in relation to the volume of harvested spruce

Time consumption for vehicle travel into a new position (t_{A121}) is defined by function (3):

$$t_{A121} = -19{,}328h^2 + 41{,}317h + 27{,}523 \qquad \text{(s/tree)} \qquad (3)$$

where:

t_{A121} time necessary for vehicle travel into a new position for harvesting spruce (s/tree)
h volume of harvested spruce (m^3/stem)

Function analysis combined with first derivative of the function indicates the function's local extreme upon stem volume 1.06 m^3/stem. We can therefore state that for stem volume ranging from 0.07 m^3 to 1.06 m^3 the consumption of time necessary for vehicle travel increases. From operational perspective, this increase can be justified by a higher density of lower age class stands where unit time consumption for this segment of work operation is lowest. Under these conditions, a higher number of trees are harvested from a single position. As tree volume increases, the number of trees per area unit decreases while tree spacing increases. Consequently, distance between felled trees as well as operation time consumption grow. Upon spruce volume exceeding 1.06 m^3/stem, travel time decreases due to tree spacing which exceeds 4 m (Decree of the Ministry of Agriculture No. 84/1996), which in turn creates a "naturally" necessary technological width required for forwarding lines and the passage of harvesters and forwarders, while minimizing preparatory felling to allow vehicle passage.

In stem volume of 0.07 m^3, time consumption for harvester travel is 30 s. Maximum time consumption t_{A121} for volume of 1.06 m^3/stem is 50 s; for the highest stem volume which was processed in the course of salvage felling (2.20 m^3/stem) the time consumption was 25 s.

The lowest time necessary for vehicle travel into a new position tends to be achieved in young and dense stands requiring high harvesting intensity. This allows minimal vehicle travel (∅ 2,5 m) and enables harvesting of several trees from a single position, which in extreme cases involved up to 10 trees.

The results also encompass non-cyclical work operations which increase time consumption per the work operation segment involving the vehicle's travel to a new position due to its travel to the felled tree and the consequent travel to process the tree which does not take place immediately after its felling. In the course measuring snapshots, 38 % of the measured trees were moved to the forwarding line. Should the cyclical production process be fully maintained, only a fractional decrease in time consumption of 0.8 s per vehicle travel to a new position (t_{A121}) would occur with every work operation. The above mentioned time losses, most frequently due to non-cyclical work operations and consequently decreased work productivity, are affected by work field width which exceeds 20 m. Vehicle operator cannot reach the work field's transport boundary from the forwarding line with the hydraulic crane and its felling head, and consequently cannot fell and process all the marked trees. Operators are forced to drive into the stand to fell trees and forward them to the forwarding line from which the trees are consequently processed. The wide spacing of forwarding lines is due to terrain anomalies which made standard stand division (8% cases) impossible. Unqualified marking of the forwarding lines in a forest stand represents a more frequent cause of non-cyclical work operations (83%). Operators were obliged to follow these lines and consequently had to drive into stands. The last registered cause was pre-felling of more immediately situated marked trees from the forwarding line, which simplified the work procedure for repeating identical work operation segments (9%). In the latter case, the production time of work operation segments was not shortened. Operators rather opted for deliberate work monotonousness to eliminate mental stress in the course of the work process.

Time for approaching the felling head and gripping the tree (t_{A122})

Time for felling head approach can be considered constant. Statistical analysis does not confirm dependence of this time on the felled tree volume. Dependence on terrain conditions cannot be supposed either. The felled tree's distance from harvester or the distance within the reach of the hydraulic crane have been identified as a major factor reflected in primary measurements t'_{A122} as well as in the calculated results t_{A122}. In spruce felling, time for felling head approach ranges from 5 to 63 s in 95 % of measured work operations. Mean time t_{A122} which is considered constant within the total work operation time is 18.7 s. This calculated value encompasses the sum of all cyclical and non-cyclical work operations in the course of which the felling head is moved to the tree twice. At the first stage it is moved to a standing tree in order to fell it prior to its transfer to the forwarding line and at the second stage to a tree lying on the forwarding line prior to its processing.

Time for felling the tree (t_{A123})

Felling is conducted with the help of a chain saw which is part of the felling head. It cannot be supposed that the work operation segment (t_{A123}) which involves felling a tree will be affected by different sequences of work segments in a work operation, i.e. cyclical vs. non-cyclical ones. The model does not encompass the total number of all measurements, as 67.3 % of all processed trees had to be excluded from mathematical/statistical analysis due to the fact that this work operation segment was had not been conducted – in windfalls and trees broken at the foot. Time consumption in trees where it was measured for this particular work operation segment was analyzed in relation to the felled trees' volume and species.

Upon the deployment of the above mentioned harvester, time for felling a tree can be expressed by the polynomial function (Fig. 2). Its behaviour, as is the case with majority of the remaining work operation segments, is described in relation to the volume and species of the felled tree. This particular time t_{A123} is expressed by the following function (4):

$$t_{A123} = -0{,}5641h^2 + 9{,}2483h + 3{,}216 \qquad \text{(s/tree)} \qquad (4)$$

where:

t_{A123} time for felling spruce (s/tree)

Time t_{A123} consumption in the lowest volume of felled stem (0.20 m^3) borders on 5 s. Time consumption for felling a tree shows an upward trend in relation to the felled stem's volume. The maximum consumption of unit time per the given work segment was 21 s in a tree with the highest volume of 2.20 m^3 (Fig. 2).

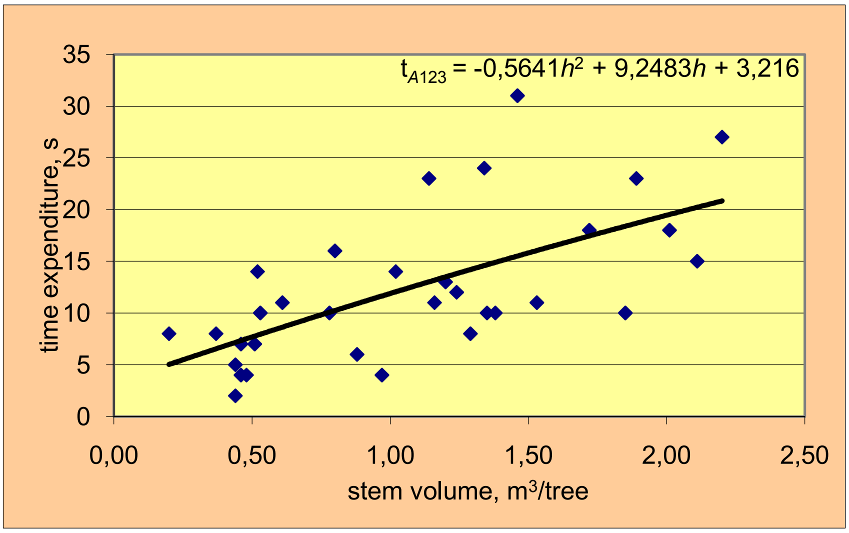

Fig. 2. Time necessary for felling a tree in relation to the felled trees' volume

Time for stem processing (t_{A124})

Time for processing felled spruce (t_{A124}) constitutes the biggest share of the work operation total time (t_{A1}). In the analyzed technology, this value ranges from 17 to 93 %. Mean t_{A124} consumption ratio in relation to the character of tree positioning is shown in Table 5.

Time consumption is independent of work operation type (cyclical, non-cyclical). Therefore the model is created from a selection set of all measurements in relation to a tree species. With regard to the harvester's analyzed time operation, time t_{A124} for tree processing represents the biggest share and its consumption increases with increasing volume of the processed trees. Time t_{A124} is defined by the following polynomial function (5):

$$t_{A124} = -3{,}0435h^2 + 54{,}463h + 28{,}623 \qquad \text{(s/tree)} \qquad (5)$$

where:

t_{A124} time for processing a tree (s/tree)

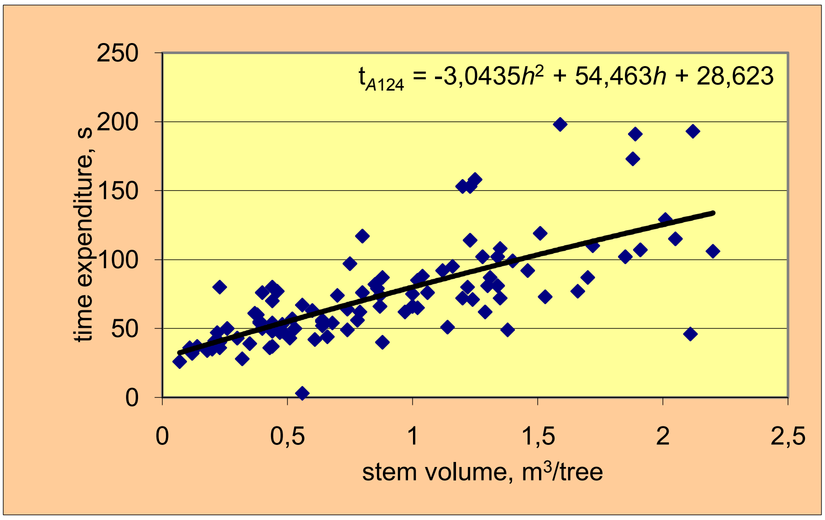

Fig. 3. Time necessary for tree processing in relation to the felled tree volume

Time for processing a felled tree increases rapidly in relation to the tree's volume and to the processed tree's branchiness. Increasing stem volume and branch diameter in places where they are cut off by the delimbing knives result in an increase in time necessary for debranching which is part of the tree processing work operation segment. Upon the processed trees' lowest stem volume of 0.07 m^3, mean time consumption t_{A124} is 32 s. The highest tree processing time consumption was measured in stem volume of 2.20 m^3 and accounted for 133 s. Among the monitored volume classes (in accordance with Table 6) we can trace an almost linear increase of 5–9% in the required unit time. The highest increase was monitored in trees whose volume exceeded 1 solid cubic meter (an increase of 10–19%) – see Fig. 3.

Time for tree transfer to the forwarding line (t_{A125})

Generally speaking, time for tree transfer represents simple skidding without consequent processing. Time for skidding cannot be measured in the course of cyclical operations, as it overlaps with the tree felling work segment (the tree is skidded already during its fall) and with timber processing work segment (during skidding the tree is already being processed by the felling head or the time for skidding is too short to be measured and therefore it is included in the tree processing segment).

The ratio of non-cyclical work operations, which encompassed transfer (skidding) time to the forwarding line, accounted for 38% measurements of the harvester's work operations and 0.5% of the total volume of measured time. Owing to the fact that it is impossible to justify and validate dependence of this time on a felled tree's stem volume, a constant value of t_{A125} has been determined as a mean value which represents 0.8 s/tree.

Work operation total time (t_{A1})

Calculations of time necessary for all implemented work operations (including the non-cyclical ones) are determined by an elementary function (6) summarizing all segments of work operations. The defined functions are approximations of functions describing time consumption in individual time segments of a work operation.

$$t_{A1j} = \sum_{i=1}^{5} t_{A12i}(h_j) \qquad \text{(s/tree)} \qquad (6)$$

where:

t_{A1j} direct labour time per j^{th} harvesting operation (s/tree)
t_{A1i} time required for i^{th} segment of a work operation (s/tree)
h_j tree volume j (m^3/stem)

The total work operation time for spruce processing by a high-powered harvester can be defined by the following function (7):

$$t_{A1} = \sum_{i=1}^{5} t_{A12i}(h) = -22{,}837h^2 + 103{,}74h + 54{,}554 \qquad \text{(s/tree)} \qquad (7)$$

The generally higher ratio of non-cyclical operations which account for 38% of spruce processing in salvage felling causes an increase of 8 seconds in mean time consumption for vehicle travel to a new position for every work operation; the time for felling head approach to a tree increases by 5 s and time for tree transfer goes up by 0.8 s. This increase accounts for 6.6–10.8% of a work operation in relation to the harvested tree's stem volume. Calculations based on the above mentioned relation reveal that total work operation time consumption in spruce harvesting is 62–172 seconds in relation to the harvested tree volume ranging from 0.07–2.20 m^3/stem (Fig. 4).
Operation time consumption per work operation is graded in relation to the volume class of felled stems (Table 6), regardless the positioning of trees prior to salvage felling. Compared with planned felling, the performance of high-powered harvesters in salvage felling decreases by 11% upon harvesting of stem volume of 0.07 m^3 up to 28% in stem volume of 2.20 m^3 [2].

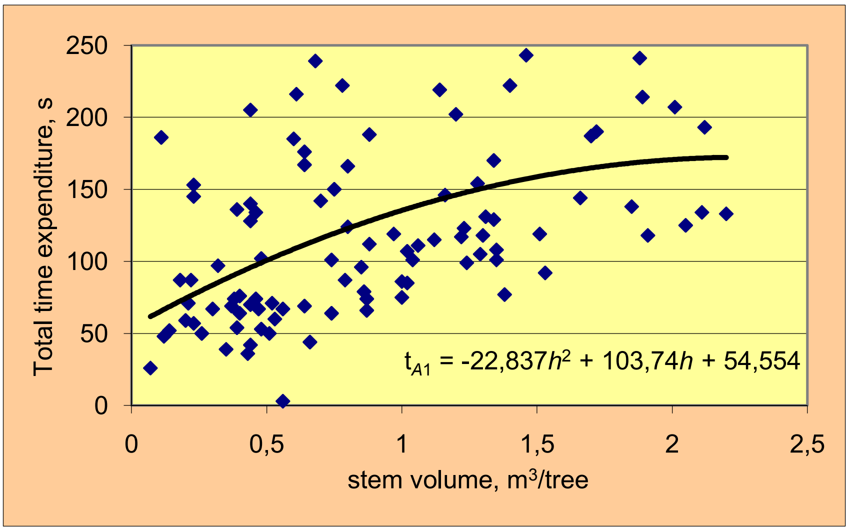

Fig. 4. Total time required for a unit work operation in relation to the harvested spruce volume

Table 6 shows a summary of harvester operation time per production unit (cubic meter). For operational purposes, hour time required for total processing of a cubic meter of timber is a priority. The highest increase of 0.24 h/m^3 in time consumption is associated with the lowest volume of harvested stems (0.05 m^3) and decreases in relation to growing stem volume, reaching 0.02 h/m^3 for stem volume of 2.00 m^3. The vehicle's operational performance per moto hour, which does not encompass other batch and shift times, accounts for 4.08 m^3/mth upon stem volume of 0.05 m^3, and 42.18 m^3/mth upon highest stem volume of 2.00 m^3.

Table 6. Time consumption per work operation (t_{A1}) – felling and processing of a tree and a solid cubic meter

Stem volume	Time consumption			
(m^3/stem)	(s/tree)	(s/m^3)	(h/m^3)	(m^3/PHM$_0$)
0.05–0.09	61.7	881	0.24	4.08
0.10–0.14	66.7	556	0.15	6.48
0.15–0.19	71.5	421	0.12	8.56
0.20–0.24	76.3	347	0.10	10.38
0.25–0.29	80.9	300	0.08	12.01
0.30–0.34	85.4	267	0.07	13.49
0.35–0.39	89.8	243	0.07	14.83
0.40–0.44	94.1	224	0.06	16.07
0.45–0.49	98.3	209	0.06	17.22
0.50–0.59	104.3	191	0.05	18.81
0.60–0.69	112.0	174	0.05	20.74
0.70–0.79	119.2	160	0.04	22.51
0.80–0.89	125.9	149	0.04	24.16
0.90–0.99	132.2	140	0.04	25.73
1.00–1.19	140.8	129	0.04	28.00
1.20–1.49	152.8	114	0.03	31.69
1.50–1.99	166.0	95	0.03	37.83
2.00 +	170.7	85	0.02	42.18

Snapshots of a harvester work day

Preliminary analyses indicate that consumption of shift and batch times accounts for 25 % of working time. This has been validated by other research papers, e.g. [2] states the ratio of operation time after deducting time losses at 65.2–77.3 %. Operation time ratio of 71 % total shift time is also corroborated e.g. by [8]. These results correspond to or border on proposed coefficients for operation time – 0.75, which are incorporated in performance standards. For other necessary activities, which are defined as shift or batch time, 15 minutes are calculated towards an hour [7].

Total time consumption and productivity of multi-function harvesters

Following previous analyses, total consumption of time required for a production unit in felling and processing of trees by a harvester is defined by the following general function (8):

$$t_n = k_C \cdot \sum_{i=1}^{5} t_{A12i}(h) \quad \text{(s/tree)} \tag{8}$$

where:

t_n total time consumption per a production unit during felling and processing a tree (s)
t_{A12i} time consumption per i^{th} segment of work operation (s)
k_c coefficient of batch and shift time for harvester operation (-)

The coefficient of batch and shift time for harvester operation encompasses times which are essential for the machine's operation as well as minimum time for legal breaks, while excluding time losses due to operator's negligence or due to technical-organizational reasons.

Total consumption of time required for felling and processing of spruce in the course of salvage felling is defined by the following function (9):

$$t_{n1} = k_{CM} \cdot \sum_{i=1}^{5} t_{A12i}(h) = -28{,}546h^2 + 129{,}675h + 68{,}193 \quad \text{(s/tree)} \tag{9}$$

where:

t_n total consumption of time for felling and processing of spruce (s/tree)
k_{CM} coefficient of batch and shift time for a harvester (-)
$k_{CM} = 1.25$

Required time consumption in harvesters ranges from 0.31–0.03 h/m^3 upon stem volume between 0.05–2.00 m^3. Under the given production conditions, the performance of a high-powered harvester reaches 3.27–33.75 m^3/h.

DISCUSSION AND CONCLUSION

Obtained results indicate that the vehicle's performance is conditioned primarily by the felled tree volume. Stem volume is a decisive variable for management purposes as well, as pricelists are created with regard to the tree volume within a forest stand and include extra charges for specific conditions with special focus on harvesting intensity and terrain slope.

When confronting resulting operation time consumption measured in the studied harvester with results of a performance calculation mathematical model which is designed for all harvester classes [9], we can see a marked difference. The interval of operation time consumption in this study ranges between 6.5–28.0 m^3/PMH_0 upon stem volume of 0.1–1.0 m^3. However, Jiroušek's model shows performance of 8.5–95.6 m^3/PMH_0 upon identical stem volume, which is 3.5 times higher. [14] analyzes the performance of nine harvesters deployed in principal felling, one of them Ponsse Ergo. In this study, the harvester's performance ranges from 6.0–39.0 m^3/Mth upon stem volume of 0.1–1.2 m^3. In this resulting value, 15 minutes were deducted as idle time due to batch and shift time losses.

Ponsse Ergo harvester was analyzed in salvage felling conducted in coniferous stands. Performance norms are designed for terrain slopes up to 10%, of good ground strength and terrain free of obstacles. The tolerable snow cover is max. 20 cm. Technical and organizational conditions define a maximum 20 meter spacing between forwarding lines to allow the 10-meter hydraulic crane to reach forest stand from the forwarding lines. The proposed work times are applicable only for estimating machine performance in closed forest stands and cannot be used for "mere" felling of border trees which tend to have more branches and thus the estimated operation time for processing is higher.

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