Influence of human factor on the time of work stages of harvesters and crane-equipped forwarders

J. Dvořák, Z. Malkovský, J. Macků

Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

ABSTRACT: Harvester technologies represent the second most common logging system in the Czech Republic. The high productivity of this technology is very necessary to cover its acquisition and operational costs. A human factor – a machine operator is the most important factor that surely influences the machine productivity. That is why the aim of this study is as follows: to analyze the mutual dependence of machine operator's education and working experience and harvester and forwarder productivity. The analysis proves that the operator's education and even more his working experience are very important. The time of harvesting work stages was measured when the harvester was operated by an operator with two-year working experience and by an operator with no experience. The average time difference between the harvester operators was 64.9 seconds in one work stage. The statistical significance of different operation times was confirmed during technically demanding segments in the working stage (the boom out the felling head and tree processing). Operators with the same working experience in forestry mechanization – about 13 years but with different education carried out the haulage work stage. In this case, the statistical significance between calculated differences was not proved. This fact proves that the operator's working experience is more important than his education.

Keywords: harvester; forwarder; work stages; job standardization

The use of a cut-to-length system with harvester technologies has increased in the Czech Republic. We estimate that at the present time there are about 200 harvesters and ca 350 forwarders in Czech forestry. This technology is at the second place – just after manual logging with power chainsaw as it accounts for ca 25% of the annual planned timber production in the Czech Republic (Malík, Dvořák 2007). We expect a progressive trend in the use of logging and haulage machinery also in future and similar development like in Western Europe, where the percentage of cut-to-length system is even 60% (Germany). The most expanded use of harvesters and forwarders is in Scandinavia with ca 90% (Moskalik 2004; Zychowicz 2005).

There are many advantages of using these machines: savings of wage costs, ergonomics and work hygiene, prompt reaction to customer requirements, minimal pollution of logged wood and a high grade of ecological quality of logging and hauling activities. On the other hand, there are also some disadvantages: work organization is quite demanding, staff training and training of qualified operators are time-consuming and expensive.

The productivity of this high-power machinery is always analyzed in relation to production factors such as volume of felled stems, hauling distance, cutting percentage and others (Forbrig 2001; Ulrich et al. 2002; Valenta, Neruda 2003; Kärhä, Rönkkö 2004; Dvořák, Karnet 2007).

Practical experience shows that an operator is the most important factor of productivity (Purfürst, Erler 2006) in conjunction with tree volume and operator's work time (Purfürst 2007). The more the mechanization, the higher concentration is needed to run the operational process. The full mechanization of production (e.g. harvester technologies) means that it is necessary to have a qualified operator (Erler 2000). Education and long-term working experience are monitored factors that influence the quantity and quality of executed work (Lukáč 2005). We can say that the human factor (operator) takes the front positions when we consider the productivity and it also influences safety at work and work cleanness in the forest.

The aim of this research was to verify differences in the productivity of harvester and forwarder operators with different or similar education or experience.

MATERIAL AND METHODS

Operator A – middle-class harvester Timberjack 1270 – skilled as a car mechanic with one-year working experience on a forwarder and one-year working experience on the mentioned harvester. Operator B finished the forestry technical school and had no working experience. There is a significant difference in both the education and the working experience between these operators.

Forwarder operators of Timberjack 1110 had different education but very similar working experience. Operator C (just a primary school) has been working with forwarder for 3 years. Before, he had been working with skidder for 10 years. Operator D was trained in mechanical engineering and he has been working with forwarder for 3 years. Before, he had been working with a machine for ground works for 15 years and with skidder for 10 years.

Important production terms and technical standards that can influence the productivity of work were eliminated using equal work conditions. The work was monitored in a forest compartment on the area of 26.37 ha, stand age range 68–72 years, spruce distribution 90–97%, spruce breast height diameter 23–25 cm, mean height 23–25 m and mean stem volume 0.47–0.60 m^3. Pine is the second main species; distribution 1–9%, breast height diameter 26 to 32 cm, mean height 23–25 m and mean stem volume 0.54–0.90 m^3. Larch, ash and birch make the rest of the species mixture. Stand density is 9. Intermediate felling was realized in conditions of terrain type 11 (slope gradient up to 8%, practicable and carrying terrain) at the time of dormancy. The stand was made accessible by hauling lines of the average width 3.8 m and distance 20–25 m. Roadside landing was located straight at the stand margin. Timber assortment of the length 2–6 m was collected there.

Segments in work stages were measured on sample plots and these measurements were used for further analysis in accordance with the standard methodology for job standardization (Klouda et al. 1962). Work stages of harvester were divided as follows:

– movement of the machine to a new position (t_{A101}) – falling of the felling head,
– to the turn-position and the harvester moving from the site of felling or timber processing to a new position; the machine stopping at the new position was the final cut-off point,
– approaching of the felling head to the trunk (t_{A102}) – elevation of the felling head to the operating position, approaching to the trunk and its clutching by feed cylinders,
– tree felling (t_{A103}) – felling-cut operation done by a cutting mechanism; the tree is directed to the direction of fall; the impact of tree on the ground is considered to be the cut-off point;
– the time needed to remove a hung-up tree is also included in the tree felling time,
– processing of tree (t_{A104}) – grapple of the trunk by the felling head, timber delimbing, solid volume evaluation and sorting, final cutting-off timber assortment and crown head was the end of the felling operation; drive-away of the machine to a new position was the cut-off point.

If we summarize the harvester chronology, we get the time of one operating cycle t_{HA}:

$$t_{HA} = t_{A101} + t_{A102} + t_{A103} + t_{A104} \text{ (sec)}$$

Work stages of haulage were divided into the following segments:

– drive-away of the forwarder from the truck landing (t_{A105}) – the hydraulic boom placing to the turn-position and drive-away of the forwarder from the truck landing; the first movement with the hydraulic boom to load timber assortment in the stand was the cut-off point,
– loading (t_{A106}) – timber assortment accumulation to the cargo space, the last log loading and hydraulic boom emplacement to the cargo space was the cut-off point,
– drive of the machine with cargo to the truck landing (t_{A107}) – drive of the forwarder to the truck landing; the cut-off point was the moment when the machine stopped to unload the cargo,
– unloading (t_{A108}) – discharge of timber assortment at the truck landing, their assortment to the piles; when the hydraulic boom was placed to the transport position, the haulage work stage was finished.

If we summarize the forwarder chronology, we get the time of one operating cycle t_{VT}:

$$t_{VT} = t_{A105} + t_{A106} + t_{A107} + t_{A108} \text{ (sec)}$$

We registered the unit time during the experimental measurements. The time was measured continuously with the stop-watch and then re-calculated to get the time really used for the segment of work stage.

RESULTS AND DISCUSSION

The experimental measurements included the consumption of working time that was necessary for

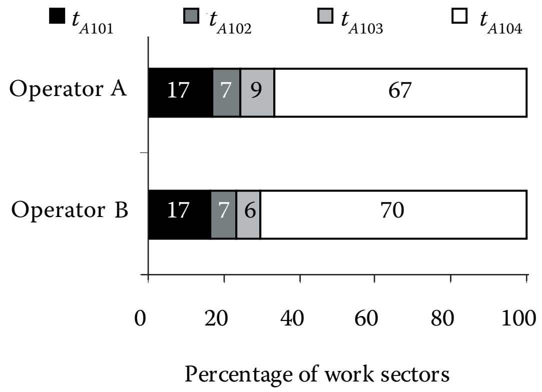

Fig. 1. Time diagram – work stage segments of harvester operators

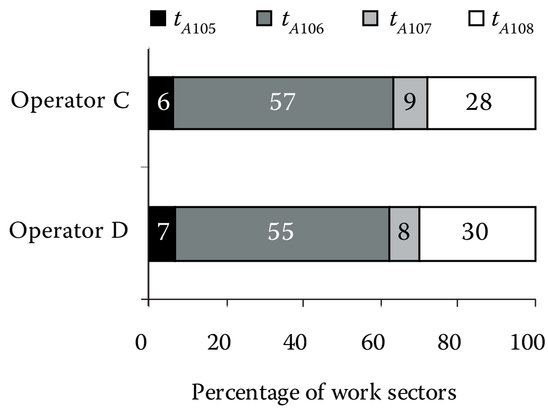

Fig. 2. Time diagram – work stage segments of forwarder operators

the operators working under the same production terms and with the equal forestry mechanization. The work of harvester operators was measured for six working days within the working shift in blocks lasting 1.2–1.5 hours. The harvesting work stage was divided into four segments. A major part of the work stage is taken by the processing of tree (t_{A104}) with 67% of the total working time used by operator A and 70% by operator B. The second most important time is the time used for the movement of the machine to a new position (t_{A101}). This part of the work stage accounts for 17% of the working time used by operator A and also B. Operator A and also B use 7% of the working time to approach the felling head (t_{A102}). As for the tree felling (t_{A103}), operator B without working experience needs the time by 2% longer (Fig. 1).

Table 1 shows the average time needed to carry out the work. The results indicate an obvious difference in the time consumption – operator B needs more time: time t_{A101} 10.4 seconds more, time t_{A102} 3.9 seconds more, time t_{A103} 1.3 second more and time t_{A104} 49.3 seconds more. It means that operator A does one working cycle (total time used for the work stage) 64.9 seconds faster than operator B.

A statistically significant difference at the significance level 0.05 can be proved only between the time for the approaching of the felling head and the time for tree processing – the most time demanding operation within the work stage. We can presuppose the statistically significant difference between these times after having done the analysis using the two-select t-test with reliability almost 100%. As these two times represent the major proportion of total production, a statistical difference in the total harvester felling time between two operators is also proved (Table 1).

The work stage of haulage was divided into four segments. The work was measured for five working shifts – 17 hours of work for operator C and 31 hours of work for operator D. The average time that was measured in one shift was 3.4–6.2 hours. A difference in the work stage segment percentage between two operators is max. 2%. The time needed for the forwarder drive-away from the truck landing

Table 1. Two-select t-test – average operation time consumption of harvester operators

Felling – work stage segments	n_A (–)	n_B (–)	ø t_A (s)	ø t_B (s)	s_A (s)	s_B (s)	t-value (–)	df (–)	p-value (–)
Machine movement to a new position			19.0	29.4	65.3	55.4	–1.557		0.12
Approaching of the felling head to the trunk			8.3	12.2	10.7	10.1	–3.470		**0.00**
Tree felling	299	123	9.4	10.7	10.8	11.5	–1.076	420	0.28
Processing of tree			75.3	124.6	34.4	73.8	–9.350		**0.00**
Total time of the work stage			112.0	176.9	77.6	98.5	–7.200		**0.00**

n_A – number of all work stages executed by operator A, n_B – number of all work stages executed by operator B, ø t_A – average time shown by operator A, ø t_B – average time shown by operator B, s_A – standard deviation of elapsed time limit in operator A, s_B – standard deviation of elapsed time limit in operator B

Table 2. Two-select *t*-test – average operation time consumption of forwarder operators

Haulage – work stage segments	n_C (–)	n_D (–)	ø t_C (s)	ø t_D (s)	s_C (s)	s_D (s)	*t*-value (–)	df (–)	*p*-value (–)
Forwarder drive-away from the truck landing			262.0	330.0	237.4	144.0	–1.101		0.28
Loading			2,319.7	2,713.3	690.4	1,024.1	–1.304		0.20
Machine drive with cargo to the truck landing	15	23	350.7	376.6	122.2	149.9	–0.558	36	0.58
Unloading			1,153.7	1,466.9	453.7	607.9	–1.707		0.10
Total time of the work stage			4,086.1	4,886.7	794.7	1,272.0	–2.171		**0.04**

n_C – number of all work stages executed by operator C, n_D – number of all work stages executed by operator D, ø t_C – average time shown by operator C, ø t_D – average time shown by operator D, s_C – standard deviation of elapsed time limit in operator C, s_D – standard deviation of elapsed time limit in operator D

to the forest stand (t_{A105}) accounts for 6–7%, time for loading (t_{A106}) is 56–57%, time for the machine drive with cargo from the stand to the truck landing (t_{A107}) is 8–9% and time for unloading (t_{A108}) is 28–30% of the total work stage time (Fig. 2).

The two-select *t*-test between average total times of operators C and D confirms the statistical significance with reliability 96%. The time of one work stage cycle increases by 13 min in the more experienced operator. It means that 81 min are needed to drive with the load from the stand to the truck landing. The mathematico-statistical analysis does not however prove the statistical significance between the work stage segments of both operators. These differences can be confirmed at the following significance levels: work stage segment t_{A105} – significance level 0.28; t_{A106} – significance level 0.20; t_{A107} – significance level 0.58. Only t_{A108} – unloading – is at the significance level 0.10, however, it is not sufficient for the set significance level 0.05 (Table 2). As for operator D, we can give the following reason for the increase in the time: a more responsible approach to the production. Timber assortment grading and preparation for haulage were on the higher level than in operator C. We can say the same about the work purity – i.e. damage in the existing stand is by ⅓ lower.

The variability of working efficiency is documented in all measured time series of harvesters and forwarders. Time measurements prove that the working rate is not the same either between operators or between the work stage times of one operator. As for operator A, the time of one working cycle for harvesting ranges from 14 to 825 seconds (Fig. 3). As for operator B, it is from 47 to 528 seconds (Fig. 4). The time for driving to the new position is most often the main reason for this variation. However, neither tiredness nor working volition in difficult field forest stand conditions can be excluded. As for forwarder operators, the time of working cycle ranges from 2,833 to 5,309 seconds in operator C (Fig. 5) and from 2,916 to 7,052 seconds in operator D (Fig. 6). Variable distances that the forwarder has to pass or

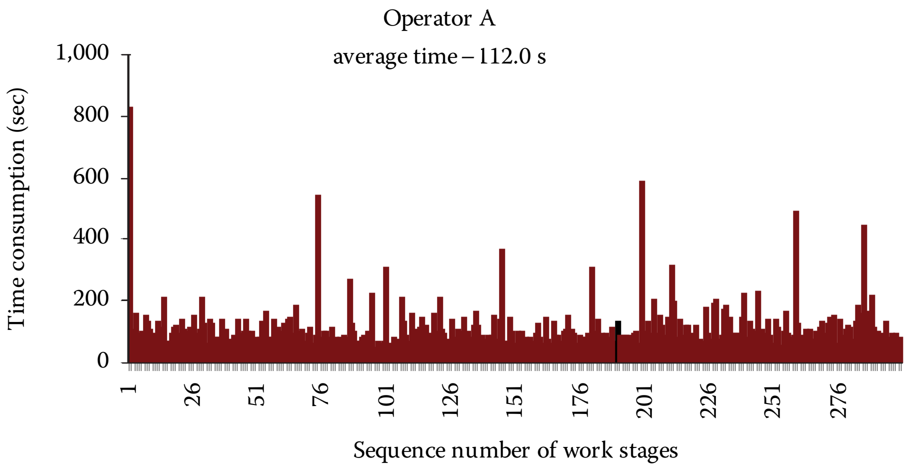

Fig. 3. Time of working cycle – harvester operator A

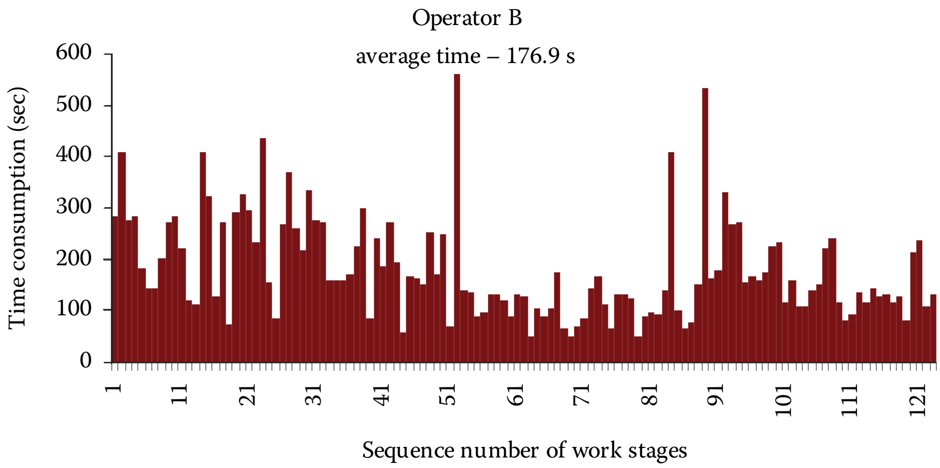

Fig. 4. Time of working cycle – harvester operator B

the time needed for assortment sorting are the main reasons. Factors such as mental stress (e.g. tiredness) cannot be excluded either.

Other shift times are also important – e.g. times of generally needful breaks, conditionally needful breaks and other idle times caused by the harvester

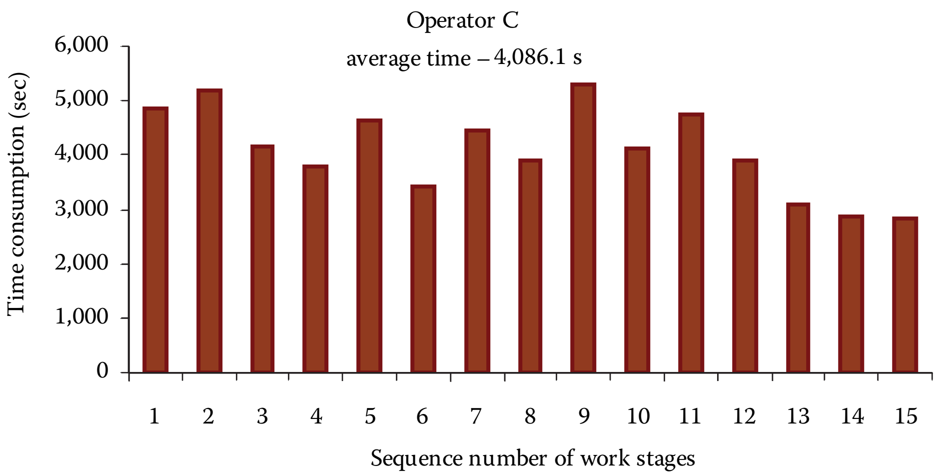

Fig. 5. Time of working cycle – forwarder operator C

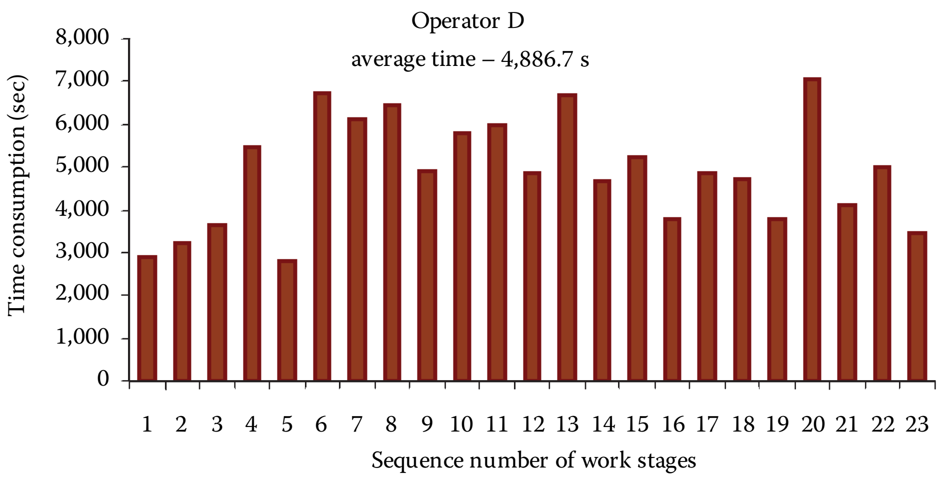

Fig. 6. Time of working cycle – forwarder operator D

or forwarder operator, eventually by technical staff organizing the work. Neither can losses caused by unavoidable casualty be excluded. All these times account for 22% of the harvester operator's shift time and 24% of the forwarder operator's time. There is no connection between these times and operators' education or working experiences. That is why a lot of studies take into account that fifteen minutes of one operating hour are used for this necessary fault time. It is the gross effective time – E_{15} (machine production time including delays shorter than 15 min). In case that the operator causes these times, his working responsibility is the main factor.

CONCLUSION

The results prove that education and even more working experiences are very important factors influencing the work stage time. There is a very close relationship between the human factor – machine operator and the time needed for one work stage.

At the significance level 0.05 there are statistically significant differences between operator A and B at work stage segments "approaching of the felling head" and "processing of the tree". The time difference is caused by the fact that operator A has two-year working experience in logging and hauling machinery (operator B has had no working experience so far). No statistically significant difference was proved between the work stage segments "drive of the machine to a new position" and "clutching the trunk and felling the tree". The reason might be that these operations are not so difficult from the technical and professional point of view.

No statistically significant difference was proved between the work stage segments of the forwarder operators. Perhaps because both operators have similar working experience with forwarder – 3 and 10 years and both used to work with skidder before.

Having judged the forwarder work stage times we are able to prove that at the significance level 0.05 there is no statistically significant difference in times needed by operators with similar working experience. This was proved in all mentioned work stage segments. It means that if we have operators with similar working experience, we can expect the equal productivity and time needed.

It is possible to recommend that more attention should be paid to the training of operators, especially to handling the hydraulic crane equipped with felling head and to timber assortment production based on technical standards of round wood supplies. Currently there is only one legislative condition for the work with harvester or forwarder – driving licence of type T for tractor. This is completely insufficient for the work with machines in question.

References

DVOŘÁK J., KARNET P., 2007. Preliminary technical time standards for harvesters working in premature and mature stands. Electronic Journal of Polish Agricultural Universities, Akademii Rolniczej in Wroclaw, *10,* Issue 1.

ERLER J., 2000. Forsttechnik. Stuttgart, UTB: 246.

FORBRIG A., 2001. Zur technischen Arbeitsproduktivität von Kranvollernter. Forsttechnische Information, Nr. 5: 22–25.

GLÖDE D., SIKSTRÖM U., 2001. Two felling methods in final cutting of shelterwood, single-grip harvester productivity and damage to the regeneration. Silva Fennica, *35*: 71–83.

KÄRHÄ K., RÖNKKÖ E., 2004. Productivity and cutting costs of thinning harvesters. Journal of Forest Engineering, *15*: 43–56.

KLOUDA M. et al., 1962. Odvětvová metodika normování výkonu v lesním hospodářství. Praha, Ministerstvo zemědělství: 139.

LUKÁČ T., 2005. Viacoperačné stroje v lesnom hospodárstve. Zvolen, TU: 137.

MALÍK V., DVOŘÁK J., 2007. Zhutnění půdy harvestorovými technologiemi. Lesnická práce, *86*: 12–14.

MOSKALIK T., 2004. Influence of cutting form on the harvester productivity and costs. In: International Symposium Mechanisierung der Waldarbeit, 37. Grunden – Vienna. Wien, BOKU: 112–118.

PURFÜRST F.T., 2007. Human Influences on Harvester Operations. In: Formec 2007 – Session – Some Experiences from Around the World. Wien, BOKU.

PURFÜRST F.T., ERLER J., 2006. The precision of productivity models for the harvester – do we forget the human factor? In: Precision Forestry in Plantations, Semi-Natural and Natural Forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa, 5–10 March 2006: 465–475.

ULRICH R. et al., 2002. Použití harvestorové technologie v probírkách. Brno, MZLU: 85.

VALENTA J., NERUDA J., 2003. Analysis of the Production Rate of Harvester Technologies in Logging Operations, Brno. In: Fortechenvi Brno, MZLU v Brně: 1–8.

ZYCHOWICZ W., 2005. Efficiency of exploitation of the vehicle that can be used alternatively as a forwarder of clam bunk skidder. Zeszyty Naukowe Akademii Rolniczej im. H. Kollataja in Cracow, Nr. 419: 291–298.

Received for publication June 29, 2007
Accepted after corrections November 23, 2007

Vliv lidského faktoru na čas pracovní operace harvestorů a vyvážecích traktorů

ABSTRAKT: Harvestorové technologie představují druhou nejrozšířenější těžební technologii v ČR. Potřeba vysoké výkonnosti této technologie je vázána na nutnost krytí jejích pořizovacích a provozních nákladů. Nejdůležitějším faktorem, který bezpochyby výkonnost stroje ovlivňuje, je faktor lidský – operátor stroje. Cílem studie je proto analýza závislosti vzdělání a praxe operátorů harvestorů a vyvážecích traktorů na pracovní výkonnost. Analýza prokazuje, že vzdělání a především praxe operátora má velice významnou úlohu. Při činnosti harvestoru byl měřen čas pracovních operací těžby dříví prováděných operátorem s dvouletou praxí a operátorem bez praxe. Průměrný časový rozdíl mezi operátory byl 64,9 sekundy na jednu pracovní operaci. Statistická významnost rozdílných výrobních časů byla potvrzena u technicky náročných úseků pracovní operace (přisunutí těžební hlavice a zpracování kmene). Pracovní operace vyvážení dříví prováděli operátoři se stejnou provozní praxí s lesnickou mechanizací po dobu 13 let, ale s rozdílným vzděláním. V úsecích pracovní operace statistická významnost mezi vypočtenými rozdíly potvrzena nebyla. Tato skutečnost potvrzuje význam praxe před samotným vzděláním operátora.

Klíčová slova: harvestor; vyvážecí traktor; pracovní operace; normování práce

Corresponding author:

Ing. Jiří Dvořák, Ph.D., Česká zemědělská univerzita v Praze, Fakulta lesnická a dřevařská, 165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 383 748, fax: + 420 224 383 732, e-mail: DvorakJ@fld.czu.cz