Operation times in John Deere 1110 E forwarders in regeneration felling

A. Kabeš, J. Dvořák, P. Natov

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

ABSTRACT: We calculated high-power forwarder productivity in regeneration felling with the objective to set long-term work plans. Based on the time studies of the forwarder operator's work operation the operation time consumption was calculated and operation standards for the studied type of forwarder were designed. The standard values were determined based on the volume weight of harvested timber and the forwarding distance. The resulting time consumption required for forwarding 1 m^3 of timber, whose mean tree volume is 0.30–0.99 $m^3 \cdot stem^{-1}$, and upon forwarding distance of 100–1,000 m ranges from 0.05–0.09 $Nh \cdot m^{-3}$.

Keywords: forwarder; work efficiency; forwarding distance; volume weight; productivity; time consumption

Harvester technology was first deployed in the Czech Republic in salvage felling induced by air pollution in the Krušné hory Mts. (Gross 1984). The first machines used were Volvo BM 971, the first generation of clam bunk forwarders. At present, the statistics of the Ministry of Agriculture of the Czech Republic estimate that a total of 670 forwarders are currently used (MZE 2013). The period between 2002 through 2012 saw a gradual increase in cut-to-length logging, which is closely related to harvester technology, from the initial 11% to 35% (Dvořák et al. 2011a; MZE 2013).

Long-term global technological developments combined with a dramatic increase in harvester technology deployment in planned logging in the Czech Republic since 2002 have inspired a number of experts to conduct analyses of harvester technology productivity (e.g. Forbrig 2001; Pausch, Ponitz 2002; Kärhä et al. 2004; Nurminen et al. 2006; Dvořák, Karnet 2007; Jiroušek et al. 2007; Spinelli, Magagnotti 2010; Komárková-Kinská, Komárek 2012; Dvořák, Walczyk 2013; Kováč et al. 2013). However, the limits of acceptable production conditions for harvester technology with respect to work efficiency have not been clearly specified so far. This requires further analyses of dependence between production conditions and time consumption, calculations of productivity and an update or extension of the existing standards adopted in 2011 (Dvořák et al. 2011b). Forest management practice requires that harvester productivity standards should be able to ensure efficient work planning and compare the harvester productivity with "traditional" logging and hauling technologies – power saws (PS), universal (UWT) or special wheeled tractors (SWT). Standards represent the simplest general means for calculating the expected productivity of individual types of technology in relation to selected production conditions.

The aim of the paper is to analyze operation time consumption for estimating the productivity of high-powered forwarders in relation to the volume of logged trees and the forwarding distance.

MATERIAL AND METHODS

The data and experimental measurements were conducted in forests subject to planned regeneration felling and managed by the Toužim Forest District. The harvested stands consisted of conifer-

Supported by the Czech University of Life Sciences Prague, Project No. A07/14.

Table 1. Identification data on workplaces

Stand	Area (ha)	Tree species	Mean height (m)	Mid diameter (cm)	Mean-tree volume (m^3)	Standing volume (m^3·ha^{-1})	Planned logging (m^3)	Type of logging
727 E 11	4.08	SM	26	25	0.62	475	494	MU
727 E 10	3.50	BO	23	26	0.54	341	304	MU
726 D 11	5.12	SM	22	23	0.45	70	94	MU
		BO	21	26	0.50	209	278	
		MD	23	28	0.67	7	9	
724 B 10	4.08	SM	26	27	0.72	362	485	MU
		MD	28	33	1.15	40	54	
5 D 11	5.12	SM	25	26	0.64	420	800	MU
728 A 9	0.45	SM	26	22	0.57	354	47	MU
728 A 10	0.74	SM	26	28	0.77	181	74	MU
		BO	25	27	0.63	111	45	

SM – spruce, BO – pine, MD – larch, MU – planned regeneration felling

ous species (spruce and pine) with admixed larch (Table 1). Three types of cut-to-length logs were produced from pine and larch and six from spruce.

Experimental measurements were conducted in a John Deere 1110 E high-powered forwarder with 136 kW maximum engine output (classification according to Lukáč 2005). For the purposes of the analysis conducted, the forwarder's basic technical parameters which may affect its productivity, including its 12 t load rating, length 9,475 mm, height 3,700 mm and width 3106 mm, are considered constant. The cross-sectional area is 4.3 m^2.

Experimental measurements and operation time analysis methodology. The time study of operator's work operations which was compiled on the basis of data from publications by Klouda et al. (1988) and Dvořák et al. (2011a) was used for gathering data necessary for registration of timber forwarding operation times. This time study was applied in consequent time consumption analysis and for normative purposes. Time consumption per work operation was measured in minutes. Each time study registered individual forwarding operations with the required time consumption necessary for performing the given work operation. The production stage of timber forwarding was divided into four work operations: driving from roadside landing (RL) to the stand, loading, driving from the stand to RL and unloading, in accordance with productivity standards (Dvořák et al. 2011a) (Fig. 1). The height and length of forwarded cut-to-length logs were measured in each load. The load-space width was known from the technical documentation of the machine. Based on these three variables, the load volume in feed meters was calculated and using a relevant coefficient converted into cubic meters.

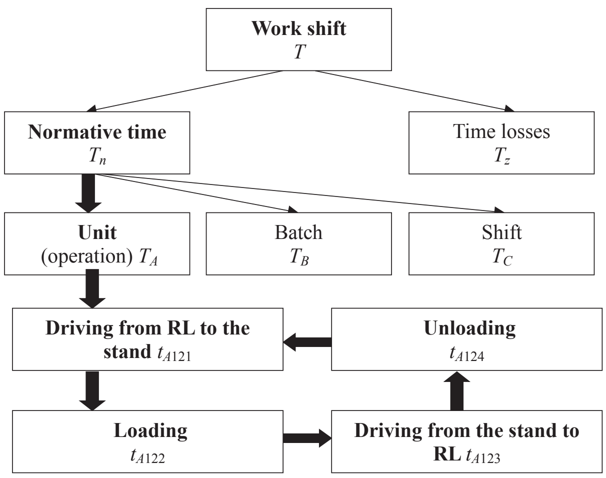

Fig. 1. Diagram of work shift stages with incorporated operation time

Production conditions at individual worksites were recorded in the harvester organization and operation manual, including worksite identification, characteristics of natural conditions, description of the logging operation and the harvested tree species, as well as the technological characteristics of the worksite and harvesting operation.

RESULTS

Significant production conditions affecting timber forwarding conducted by forwarders made by companies listed above include: natural conditions (particularly the species composition of forest stands, mean-tree volume), technological conditions (particularly the type of logging operation, forwarding distance), technical conditions (load-space volume), terrain conditions (particularly slope inclination, bearing capacity, obstacles). The ideal environments for deploying harvester technology include coniferous monocultures, large-scale stands regardless of the planned logging type, in easily accessible terrains with suitable natural conditions (flatlands, grounds with good bearing capacity, accessible terrain without obstacles). At present, harvester technology is increasingly used in incidental felling. Most harvesters therefore operate in conditions different from those recommended for their deployment (sloping and broken terrains, etc.). These factors have a major impact on the harvester technology productivity (Table 2).

The experimental measurements in the selected region were conducted exclusively in field conditions recommended by technological typification by Simanov et al. (1993). The produced nominal log length ranged from 2 to 4 m for pine, 2–4 m (exceptionally 5 m) for larch and 2–5 m for spruce. The ratio of produced logs with respect to tree species is shown in Table 2. A total of 146 forwarded loads were monitored in the course of measurements, their average volume amounting to 12.15 m^3.

Operation time consumption

As a rule, standards and forwarding productivity are calculated from productivity standards based on the mean-tree volume and skidding or forwarding distance. Owing to this, these two factors were considered a priority for timber forwarding as well. Operation conditions and statistical analyses indicate that forwarding distance and volume weight of the logged stems have the most significant impact on forwarder operator productivity (e.g. Valenta, Neruda 2004).

The experimental data measured in production units (Table 3) allowed the construction of a model for calculating the operation time consumption. The time is defined by a multiple linear regression function (Eq. 1) expressing the consumption of given time in relation to the mean stem volume and the forwarding distance.

$$t_{A1} = 37.1684 + 0.0338L - 1.5851h \quad (1)$$

where:

t_{A1} – operation (unit) time consumption for the production stage of timber forwarding (min·load^{-1}),

L – forwarding distance (m),

h – volume weight of logged trees (m^3·stem^{-1}).

The function above allows us to infer the time consumption per forwarded unit (m^3) (Eq. 2)

$$t_{Am} = \frac{37.1684 + 0.0338L - 1.5851h}{60V} \quad (2)$$

where:

t_{Am} – operation time consumption for forwarding a volume unit (h·m^{-3}),

V – average load volume (m^3·load area^{-1}).

The course of the function is depicted by the diagram of unit time consumption (Fig. 2) at the production stage of forwarding in relation to forwarding distance and volume weight of the logged trees. The operation time consumption ranges from 0.05 to 0.09 h·m^{-3}, or from 40 to 69 min/load upon the interval of logged mean stems from 0.30 to 0.99 m^3·stem^{-1}and forwarding distance from 100 to 1,000 m.

Basic productivity standards

The proposed productivity standards of time consumption in timber forwarding are designed from time studies based on work operations analysis and extended to include the batch and shift time coefficient 1.11 (Table 4). The standards are

Table 2. The ratio of produced assortments (%) according to the nominal log length of tree species

	Nominal log length (m)							
	2	2.45	3	3 SL*)	4	4.50	5	other
Spruce	5.2	4.3	7.4	3.7	13.3	5.3	20.2	0.4
Pine	7.6	1.5	1.3		24.8			
Larch	0.1	1.2			2.7		0.1	
Others	0.5							

*)SL – saw logs 3.6 or 4 m long

Table 3. Measured values of work shift stages in timber forwarding

Shift number	Stand	Tree species	Mean of the logged tree ($m^3 \cdot stem^{-1}$)	Mean forwarding distance (m)	Unit	Shift	Batch	Loss	Normative	Volume of forwarded load (m^3)
					time (h)					
1	727 E 11	SM	0.59	80	9.62	0.08	0.17		9.87	148.30
2	727 E 11	SM	0.59	80	7.68	0.50	0.50	0.53	8.68	124.04
3	727 E 11	SM	0.59	350	10.17	0.08	0.75		11.00	90.73
4	727 E 11	SM	0.59	350	4.53		0.50		5.03	37.64
	727 E 10	BO	0.49	540	2.13		0.25		2.38	13.01
5	727 E 10	BO	0.49	540	8.63	0.50	0.75	0.16	9.88	80.08
6	727 E 10	BO	0.49	540	6.40	0.50	0.50	4.61	7.40	88.54
7	726 D 11	BO	0.48	750	7.63	0.12	1.00	0.61	8.75	141.75
8	726 D 11	BO	0.48	750	2.41		0.34	0.13	2.75	35.30
	726 D 11	MD	0.67	750	1.08		0.34	0.14	1.42	17.42
	726 D 11	SM	0.48	750	5.39	0.15	0.34		5.88	104.15
9	724 B 10	MD	0.96	120	1.14	0.50		0.03	1.64	22.62
	724 B 10	SM	0.81	120	1.53			0.10	1.53	41.99
	724 B 10	SM	0.81	410	5.87			1.13	5.87	120.24
10	822 D 10	SM	0.40	320	1.40	0.45			1.85	11.41
	822 D 10	BO	0.44	320	1.00				1.00	19.03
	821 G 13	BO	0.51	920	1.07				1.07	14.48
	821 G 13	SM	0.36	670	2.47				2.47	46.15
	821 G 13	BO	0.51	670	4.28				4.28	65.45
11	821 G 13	BO	0.51	920	1.08	0.27	0.16		1.51	15.25
	821 G 13	BO	0.51	670	6.73		0.17		6.90	114.92
	821 G 13	SM	0.36	670	2.36		0.17		2.53	24.05
12	5 D 11	SM	0.47	50	2.57	0.32	0.77	0.46	3.66	46.84
13	5 D 11	SM	0.47	150	3.87	0.52	0.67	0.30	5.06	71.59
	5 D 11	SM	0.47	90	4.92		0.68		5.60	116.46
	5 D 11	BO	0.47	150	0.13				0.13	
	5 D 11	BO	0.47	90	0.13				0.13	
14	728 A 9	SM	0.37	230	4.07	0.43	0.16		4.66	47.52
	728 A 10	SM	0.47	20	2.64	0.07	0.16		2.87	82.32
	728 A 10	BO	0.61	20	0.72				0.72	17.35

SM – spruce, BO – pine, MD – larch

designed for volume classes and intervals of forwarding distances used by Forests of the Czech Republic, State Enterprise (Dvořák et al. 2011a). The conclusions cannot be fully generalized. The standards are therefore valid for timber forwarding in planned regeneration logging operations conducted by forwarders in the conditions of the Toužim Forest District and in regions with similar production conditions.

The time consumption for cut-to-length log forwarding by medium-sized forwarders is 0.05–0.09 $h \cdot m^{-3}$ upon forwarding distance of 100–1,000 m, upon mean-tree volume 0.30 – 1.00 $m^3 \cdot stem^{-1}$ and average load volume 12.15 m^3.

DISCUSSION AND CONCLUSIONS

The deployment of the given means of mechanization (forwarders) is affected by the character of the workplace, where forwarding distance, the volume of logged trees (e.g. Dvořák et al. 2011a, Valenta, Neruda 2004) and the related volume of produced and forwarded logs are of crucial importance. The choice of skidding technology also reflects the given forest terrain and type of habitat (e.g. Bombosch et al. 2003). Frequently, access opportunities (timber transport roads, forwarding lines, roadside landings) to given work places are not taken into account (Malík, Dvořák 2007).

Table 4. Operation time consumption of John Deere 1110 E high-powered forwarder in coniferous and deciduous softwood – green by timber harvesting, timber forwarding in 2–5 m

L (m)	H (m^3)		
	0.30–0.49	0.50–0.69	0.70–0.99
	time consumption (h·m^{-3})		
0–100	0.06*	0.05*	0.05**
101–200	0.07*	0.06**	0.05*
201–300	0.07*	0.06**	0.06**
301–400	0.07*	0.07**	0.07**
401–500	0.07*	0.07**	0,07*
501–600	0,07*	0,07*	0.07**
601–700	0.07*	0.07*	0,07*
701–800	0.08*	0.07*	0.07*
801–900	0.09**	0.08*	0.08*
901–1,000	0.09**	0.09*	0.09**
Each 100	0.01*	0.01*	0.01*

H – mean-tree volume, L – forwarding distance, *real work times measured in the field in the given interval for independent variables; **simulated times according to Eq. (2)

The Toužim Forest District and its particular units are relatively fragmented due to a prolonged process of land restitutions and as such required frequent driving between the particular work places (up to several kilometres) recently. Work planning is more demanding and has to take account of stand accessibility throughout the year with respect to farmed land in the vicinity of forests. Fragmentation of forests and their tenancy represent additional factors which make work more difficult.

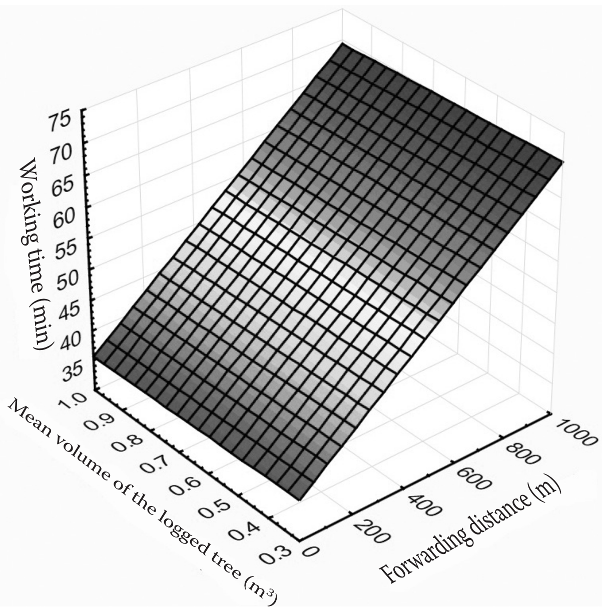

Fig. 2. Work time consumption in large forwarders for timber forwarding operation in relation to forwarding distance and weight of logged trees

The results of conducted experimental measurements formed a basis for the proposed time standards for the given and similar production conditions. The time consumption of high-powered forwarders ranges from 0.05 to 0.09 h·m^{-3} upon a forwarding distance of 100–1,000 m and average load is 12.15 m^3. Based on the designed model, the expected productivity is calculated at 9.6–17.5 h·m^{-3}. If shift (T_C) and batch times (T_B) are included (11% of shift duration), the shift productivity will range from 87 to 158 h·m^{-3} upon an average shift length of 9.04 h.

A work operation (T_A) of high-powered forwarders takes 46.9 min on average (0.78 h). The time consumption for driving a large forwarder (t_{A121} and t_{A123}) is 12.07 min (0.20 h), which represents 26% of the entire production stage. Loading and unloading (t_{A122} and t_{A124}) take up 34.08 min (0.58 h), which accounts for 74% of the entire work operation time consumption.

The deployment of high-powered forwarders in harvester-conducted regeneration felling seems rational, as forwarders register the highest work productivity in this case. On the other hand, deployment of small forwarders teamed with harvesters seems more suitable in thinning operations. Small forwarders also find considerable application in incidental felling, particularly in the processing of individual trees.

References

Bombosch F., Sohns D., Nollau R., Kanzler H. (2003): Are forest operations on steep terrain (average of 70% slope inclination) with wheel mounted forwarders without slippage possible? Available at http://formec.boku.ac.at/images/proceedings/2003/47_bombosch_etal.pdf

Dvořák J., Walczyk J. (2013): Productivity of timber harvest with the use of a harvester and a chainsaw. Sylwan, ***157***: 171–176.

Dvořák J., Bystrický R., Hošková P., Hrib M., Jarkovská M., Kováč J., Krilek J., Natov P., Natovová L. (2011a): The Use of Harvester Technology in Production Forests. Kostelec nad Černými lesy, Lesnická práce s.r.o.: 156.

Dvořák J, Kuchta T., Kabeš A. (2011 b): Výkonové normy pro malé vyvážecí traktory. [Productivity standards for small forwarders.] Lesnická práce, ***90***: 151–153.

Dvořák J., Karnet P. (2007): Preliminary technical time standards for harvesters working in premature and nature stands. Available at http://www.ejpau.media.pl/volume10/issue1/art-01.html

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

Gross J. (1984): Zhodnocení použitých mechanizačních prostředků v těžebně_dopravním procesu u Severočeských státních lesů. [Assessment of Means of Mechanization Used in the Logging and Hauling Process in North Bohemian State Forests.] Praha, VŠZ Praha: 127.

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.

Kärhä K., Rönkkö E., Gumse S. (2004): Productivity and cutting cost of thinning harvester. International Journal of Forest Engeneering, ***15***: 43–56.

Klouda M., Syrovátka K., Bluďovský Z. (1988): Normování práce. [Work Standardization.] Praha, MZLVH ČR: 208.

Komárková-Kinská V., Komárek M. (2012): Harvester technologies in mountainous conditions. Available at http://www.ejpau.media.pl/volume15/issue1/abs-08.html

Kováč J., Krilek J., Dvořák J., Natov P. (2013): Research on reliability of forest harvester operation used in the company Lesy Slovenskej Republiky. Journal of Forest Science, ***59****:* 169–175.

Lukáč T. (2005): Viacoperačné stroje v lesnom hospodárstve. [Multi-Operation Machinery in Forest Management.] Zvolen, TU Zvolen: 134.

Malík V., Dvořák J. (2003): Zhutnění půdy harvestorovými technologiemi. [Harvester-technology induced soil compaction.] Lesnická práce, ***82***: 212–214.

MZE (2013): Zpráva o stavu lesa a lesního hospodářství za rok 2012. [Report on the Condition of Forests and Forest Management in the Czech Republic in 2012.] Praha, MZE ČR: 132.

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

Pausch R., Ponitz K. (2002): Harvesterleistung und Hiebsbedingungen. Forst und Technik, ***14***: 10–14.

Simanov V., Macků J., Popelka J. (1993): Nový návrh terénní klasifikace a technologické typizace. [A new proposal of terrain classification and technological typification.] Lesnictví – Forestry, ***39***: 422–428.

Spinelli R., Magagnotti N. (2010): Performance and cost of a new mini-forwarder for use in thinning operations. Journal of Forest Research, ***15***: 358–364.

Valenta J., Neruda J. (2004): Forwarder als wichtiger Faktor der Arbeitsproduktivität in hochmechanisierter Forstnutzung. In: 37. Internationales Symposium Mechanisierung des Waldarbeit – FORMEC 2004. Gmunden, 8.–10. September 2004. Wien, Institut für Forsttechnik Wien: 108–113.

Received for publication May 12, 2014
Accepted after corrections June 12, 2014

Corresponding author:

doc. Ing. Jiří Dvořák, Ph.D., Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 1176, 165 21 Prague 6-Suchdol, Czech Republic; e-mail: dvorakj@fld.czu.cz