139. Jahrgang (2022), Heft 3, S. 221–238

Austrian Journal of Forest Science
Centralblatt für das gesamte Forstwesen

Verification of forwarders' performance standards currently being used in the Czech Republic

Überprüfung der Zuverlässigkeit angewendeter Leistungsstandards für Tragschlepper in der Tschechischen Republik

Ondřej Nuhlíček[1*], Radim Löwe[1], Martin Jankovský[1], Jiří Dvořák[1]

Keywords: productivity, time study, mechanical availability, criteria and indicator

Schlüsselbegriffe: Produktivität, Zeitstudie, Geräteverfügbarkeit, Kriterien und Indikatoren

Abstract

It has been more than ten years since the forwarders' productivity standards were created for use in conditions of the Czech forestry. Changes in assortment composition, outbreaks of bark beetle *Ips typographus*, market demands, characteristics of the forwarders used in the Czech Republic, improvements of operators' skills and working techniques lead to the question of the validity of the standard in current conditions. We compare the observed productivity and the productivity given for the working conditions by the existing standard on eight forwarders. Compliance with the standard ranged between 72 and 198%. For seven of the forwarders, there is a significant difference between observed and standard productivity. Four machines were observed in detail to calculate the productive machine hour performance and compare the shift time components with different authors. A significant difference was observed in most cases. Compared with current Czech standards, the difference in the productive work time, which is the primary operational time of the shift, was between -8.3 and +12%. Currently used standards are not accurate in observed production conditions. Productive machine hour productivity estimate form standards

[1] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Praha 6, Czech Republic
*Corresponding author: Ondřej Nuhlíček, nuhlicek@fld.czu.cz

are valid only for small-scale forwarders in up to 60 kW classes. Standard coefficients for conversion between productive and scheduled machine hour productivity are no longer adequate.

Zusammenfassung

Seit der Entwicklung von Leistungsstandards für die Bedingungen in der tschechischen Forstwirtschaft sind mehr als zehn Jahre vergangen. Änderungen in der Nachfrage und Produktion unterschiedlicher Holzprodukte, Kalamitäten durch *Ips typographus*, die Einführung eines neuen Tragschleppers in der Tschechischen Republik, die Verbesserung der Fähigkeiten der Tragschlepperfahrer/innen und Änderungen der Arbeitsverfahren führen zu der Frage, ob die aktuellen Leistungsstandards noch geeignet sind. Für acht Tragschlepper wurde die tatsächliche Leistung unter kontrollierten Produktionsbedingungen mit der Leistung nach Leistungsstandards verglichen. Die Leistungsstandards wurden in einem Bereich zwischen 72–198 % erfüllt. Für sieben Forstmaschinen wurden statistisch signifikante Unterschiede zwischen geplanter und tatsächlicher Leistung ermittelt. Vier Maschinen wurden detailliert studiert, um die reine Arbeitsleistung zu bestimmen sowie den prozentuellen Anteil der einzelnen Schichtzeiten mit den Modelldaten anderer Autoren zu vergleichen. In den meisten Fällen konnten statistisch signifikante Unterschiede zu den Modellwerten festgestellt werden. Der Unterschied in der Betriebszeit im Vergleich zu den genutzten Leistungsstandards lag zwischen 8,3 % und 12 %. Daraus lässt sich ableiten, dass die verwendeten Leistungsstandards für die aktuellen Produktionsbedingungen nicht exakt sind. Die in den Leistungsstandards definierte Stundenarbeitsleistung trifft nur auf leistungsschwache Tragschlepper mit einer Motorleistung bis zu 60 kW zu. Die verwendeten Koeffizienten zur Umrechnung der Nettostundenleistung in Bruttostundenleistung und umgekehrt entsprechen nicht der Realität.

1 Introduction

In the Czech Republic, approximately 29 – 38% of the total annual volume of harvested timber has been processed since 2011 using the cut-to-length (CTL) logging method (Dvořák *et al.* 2019). In recent years, this share has been decreasing. The volume of timber processed by the CTL logging method decreased to 34% (6.57 million m^3 in 2017) of the harvested timber volume (MZe 2018). In 2018, due to bark beetle calamities, this share fell further to 32%, albeit the total volume of timber harvested by the CTL logging method increased to 8.30 million m^3 (MZe 2019).

CTL is closely connected with the use of harvesters and subsequent forwarding of timber by forwarders. The Report on the State of Forestry in the Czech Republic in

2018 lists 1180 forwarders in forestry operations in the Czech Republic (MZe 2019). The trend of harvester technology and related timber forwarding is increasing in all European countries, although the extent of use varies in regions depending on economic trends (Moskalik *et al.* 2017). Though primarily connected to the harvesters, forwarders are often used in combined technologies to extract the timber after chainsaw logging, such as individual production (Laitila *et al.* 2007).

Labour productivity plays a crucial role in logging operations planning and related logistics (Nurminen *et al.* 2006; Dvořák *et al.* 2011; Dvořák *et al.* 2019). Its correct estimation for the given production conditions allows maximum utilisation of mechanisation and corresponding operations pricing. Therefore, productivity studies and the subsequent establishment of the productivity models are necessary to efficiently deploy logging machinery in forest operations (Stankic *et al.* 2012).

Two approaches are used to estimate the performance of the machine. The first is detailed modelling of individual work operations. The variables with the most significant influence on the operation are identified and incorporated into the models concerning the forwarders' performance classes. However, the performance class thresholds are subject to change, and this machine classification changes over time with regard to the development of mechanisation (Jiroušek *et al.* 2007; Lukáč 2005; Dvořák *et al.* 2011). Besides terrain conditions variables – terrain slope, obstacles, and soil bearing capacity (Eriksson and Lindroos 2014; Manner *et al.* 2016), logging conditions variables have a significant impact. Kuitto *et al.* (1994) emphasise, among other things, the effect of the density of the logs along the forwarding trail. Such variables are determined by the characteristics of the logged trees (*e.g.* volume of harvested logs) or by production conditions and supplier-customer relations (*e.g.* the number of produced assortments). Human factor, that is, the harvester or forwarder operator in connection to their experience, qualification or workload, is essential too (*e.g.* Neruda and Valenta 2003; Berger 2003; Natov and Dvořák 2016).

With a relatively high coefficient of determination, the combined operational time can be calculated by combining models for individual work operations. For most operations, times can be predicted accurately, but probably due to the quality of work of the harvester operator and the variation in the number of assortments, the coefficient of determination (R^2) is lower for the cargo assembly operation, where (Nurminen, Korpunen, and Uusitalo 2006) report R^2 0.58 for clear-cutting and 0.59 for thinning. Jiroušek *et al.* (2007) report R^2 range from 0.52 to 0.63 for forwarders' first and second performance classes. However, there is a problem with using these models because many variables are not known before the harvest. Alternatively, the authors' findings are tied to the analyses in the GIS environment – calculations of the average slope, timber density along the forwarder's path, obstacles, *etc.* Such models often do not consider batch or shift times, accounting for delays is problematic and using such models in the planning stage of the harvest is not a viable option for many enterprises.

The second approach to estimate machine performance is the long-term analysis of labour productivity at the shift level. In contrast to the first approach, the variables used in these models are available during planning. In particular, it is the distance and the volume of the cargo (Jiroušek *et al.* 2007; Dvořák *et al.* 2011; Proto *et al.* 2018). These studies also provide information on supportive work and non-work times, but their R^2 is usually lower. Dvořák *et al.* (2011) give R^2 for the unit (operational) time consumption between 0.24 and 0.42 in the analysis of the dependence on the volume of the stem and the distance for the performance classes of forwarders up to 60 kW and from 61 kW.

Ideally, both methods are used to estimate productivity correctly. In the case of the study of operational times, resulting in theoretical operational efficiency, the works often use a generally accepted coefficient (Stankic *et al.* 2011; Eriksson and Lindroos 2014) to convert to scheduled machine hours (SMH) performance. However, publications about utilisation rates (as a ratio of productive machine hours and scheduled machine hours) show that machine utilisation rates vary widely (Holzleitner *et al.* 2011; Ghaffariyan 2015).

For productivity estimation, Performance Standards for the Harvester Node (hereinafter referred to as "PSHN") (Dvořák *et al.* 2011) are used in the Czech Republic. These standards are based on the engine power average log volume and forwarding distance. Factors such as terrain, forest stand conditions, soil conditions etc., can be accounted for as percentage surcharges or deductions from the primary standard productivity. However, PSHN were based on the older generation of machines and timber production conditions, which differs from the conditions in Czech forestry in recent years. As Nordfjell *et al.* (2019) conclude in their study, the technological changes in the forwarders are substantial. Therefore, the revision of the standards is in order. The aims of this study are: (1) to verify the labour productivity standards used in the Czech Republic on current forwarders working in the Czech Republic and for the current assortment mix that might have changed since the creation of the standards (Nurminen *et al.* 2006) on operational data, and (2) to compare the standards with other available standards and published data on the time distribution between shift elements, that are available for the production conditions and standards system similar to those in the Czech Republic as changes in the generation of the used forwarders might affect the repair times etc.

2 Material and methods

For this study, we used the data from eight forwarders monitored in the previous five years. Table 1 gives a basic overview of forwarders and working conditions. The power classes were assigned, according to Athanassiadis (1999), using the engine power as a deciding factor. This was done mainly because the performance standards in question use engine power as a classification criterion. Forest stands aged between 37 and 150 years were either thinned or clear-cut. Four machines (Vimek 606T, Novotný LVS 5, John Deere 1010E and Timberjack 810B) were closely observed, and the individual shift – times of forwarders were monitored. These machines represent the typical mix of the machines used in the Czech Republic, where most of the machines are in lower performance classes. All of the forwarders are owned by small businesses and are not part of the large enterprise fleet, unlike in a recent study on forwarders in the Czech Republic (Dvořák *et al.* 2021). Additionally, four other machines were observed in minor detail to establish a larger sample for general productivity comparison. Only timber volume per shift and shift length data were recorded for those four machines (John Deere 810D, John Deere 810E, John Deere 1010E and John Deere 1010E).

Table 1: Basic information about the studied forwarders and production site conditions. u.b. means under bark, T thinning and C clear cut.

Tabelle 1: Grundlegende Informationen zu den studierten Tragschleppern und Produktionsbedingungen. u. b. bedeutet ohne Rinde, T Durchforstung und C Kahlschlag.

Machine number	Machine	Power	Load capacity	Power class	Type of felling	Average log volume	Number of recorded shifts	Load volume	Average forwarding distance	Average slope
-	-	(kW)	(t)	-	-	(m^3 u.b.)	(n)	(m^3 u.b.)	(m)	(%)
1	Vimek 606T	18	3	I	T	0.16	10	353	255	8
2	Novotný LVS 5	52	5	I	T	0.36	8	345	288	24
3	John Deere 1010E	115	11	II	T	0.23	15	783	350	18
4	Timberjack 810B	82	8	I	C+T	0.49	12	716	479	21
5	John Deere 810D	86	9	I	T	0.09	3	237	323	16
6	John Deere 810E	95	9	II	C	0.18	3	291	287	7
7	John Deere 1010E	115	11	II	C	0.18	3	300	341	5
8	John Deere 1010E	115	11	II	C	0.54	14	1261	427	8

Fig. 1 shows the locations of the forwarders with an indication of spruce-dominated stands; however, because of the age, restrictions of the national parks and terrain conditions, this should not be considered a map of stands where the deployment of the forwarders is possible. The shift-time elements used are the same as described in more detail by Dvořák *et al.* (2011), but in general, they are compatible with IUFRO nomenclature (Björheden and Thompson 1995). Times were recorded in forms together with the volume of cargo measured in timber stacks according to the standards of the Czech Republic (Svaz zaměstnavatelů dřevozpracujícího průmyslu 2007). From these data, together with records of production conditions of each shift, the standardised time consumption was calculated according to the Performance Standards for the Harvester Node (hereinafter referred to as "PSHN") (Dvořák *et al.* 2011). These standards are the main performance standards for harvesters and forwarders in the Czech Republic. In tabular form, they show the expected productivity of the machine, given its type, power class and overall conditions. This standard also includes deductions and surcharges for the productivity in special conditions – for example, in steep terrain or when machine operators are to be extremely careful around the undergrowth. Due to the working conditions in this study, no surcharges or deductions for working in a demanding condition had to be applied. Then, these standardised productivity values were compared to the observed productivity using a paired t-test. The comparison was made separately for each machine and the combined dataset. For forwarders where operational time data were available, the comparison was subsequently made only for this time, not considering other times. In this case, the time from the standards was converted by a coefficient of 1.31 as reported in the PSHN (which equals a machine utilisation rate of 76% to standard operational time).

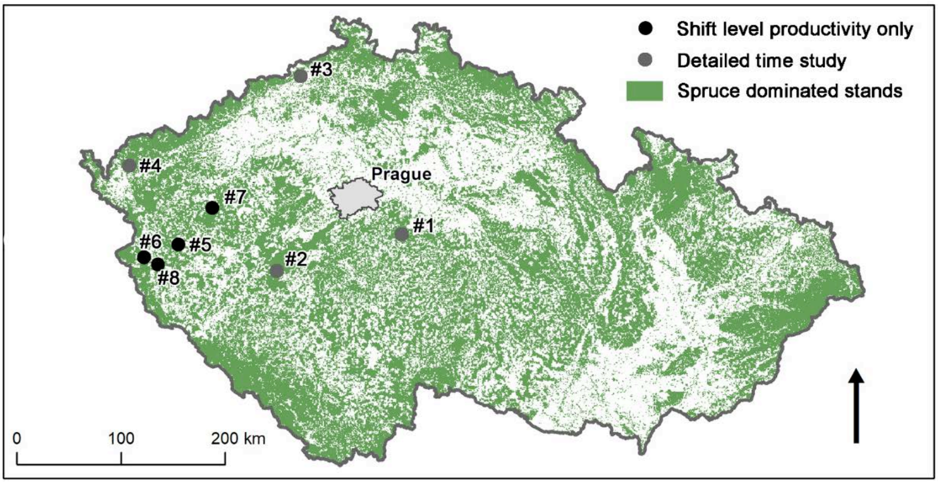

Figure 1: Locations of the individual studied forwarders and spruce-dominated stands in the Czech Republic (source of the layer - M. Kantorová, data source ÚHÚL Brandýs nad Labem).

Abbildung 1: Übersichtskarte der zum Einsatz gekommenen, studierten Tragschlepper und fichtedominierten Bestände in der Tschechischen Republik (Kartenquelle: M. Kantorová, Datenquelle: ÚHÚL Brandýs nad Labem).

In the second part of the study, the percentage distribution of the shift times was compared to the "model" distributions from PSHN and distributions published by other authors that conducted their investigations in similar production conditions (Javůrek and Dvořák 2018; Stankic *et al.* 2012). The shift times, converted to percentages, were tested using an unpaired t-test with a null hypothesis of equality of the mean observed percentage and the expected percentage of the model. The statistical software R (R Core team 2017) was used for all statistical tests with a significance level of $\alpha = 5\%$.

3 Results

3.1 Overall productivity analysis

A total of 68 work shifts were monitored, during which the 4,288 cubic meters under bark (m^3 u.b.) of timber was forwarded to the roadside landings. In seven out of eight cases, the differences between the actual and standard performance of the forwarders were significant. The combined data also show a statistically significant difference between the actual and standard performance (Table 2). Significantly different real productivities, compared to the standard productivities, were observed for two out of four machines where PMH productivity was calculated (Table 2).

Table 2: Comparison and statistical evaluation of the Performance Standards for the Harvester Node (Dvořák et al. 2011) standard compliance and statistical comparison of PMH (Productive machine hour) performance. The p-values highlighted in bold represent statistically significant differences between the actual performance and the standard.

Tabelle 2: Vergleich und statistische Auswertung der Erfüllung der Leistungsstandards für eine Harvestertechnologie (Dvořák *et al.* 2011). Die hervorgehobenen *p*-Werte stellen einen statistisch signifikanten Unterschied zwischen der tatsächlichen und der Standardleistung dar. Statistischer Vergleich der PMH (Nettoarbeitsleistung).

Machine number	Average real productivity	Average real/normative productivity	Average recorded load volume	Average load volume used in standards	*p-value*	Average PMH productivity	Average PMH / normative PMH	*p-value*
	(m^3 h^{-1})	(%)	(m^3)	(m^3)		(m^3 h^1)	(%)	
1	7.16	143	2.9	3.1	**0.015**	7.62	115	0.015
2	4.05	128	3.2	3.1	**0.030**	4.09	99	0.030
3	4.35	72	11	12.1	**<0.001**	7.86	72	<0.001
4	4.92	75	8.6	12.1	**<0.001**	6.93	73	**<0.001**
5	13.21	107	8.8	12.1	0.247		-	-
6	19.52	153	10.8	12.1	**<0.001**		-	-
7	24.76	198	11.1	12.1	**<0.001**		-	-
8	12.88	119	12.2	12.1	**0.032**		-	-

Small-capacity forwarders (#1 – Vimek 606T and #2 – Novotný LVS 5) showed no differences between actual and standard productivity. For #3 (John Deere 1010E) and #4 (Timberjack 810B), PSHNs overestimated the machine productivity in observed production conditions (10.67 m^3 h^{-1} real productivity vs. 14.81 m^3 h^{-1} according to PSHN for #4; 7.87 m^3 h^{-1} vs 13.69 m^3 h^{-1} for #3). Although these were thinnings, where a lower performance was to be expected, even with a percentage adjustment of +10% of the standards stated in the standards, this was still a significant difference.

Table 3: Percentage distribution of shift time into individual shift-time components observed during the forwarders' operations and the model percentages from different authors. Note: A – PSHN (2011); B – Stankić et al. (2012); C – Javůrek, Dvořák (2018).

Tabelle 3: Prozentuelle Verteilung der Schichtzeiten der studierten Forstmaschinen gegenüber der Modellverteilungen durch andere Autoren: A – PSHN (2011); B – Stankić *et al.* (2012); C – Javůrek, Dvořák (2018).

Shift-time component (IUFRO designation)	Machine number				Model distributions		
	1	2	3	4	A	B	C
	(%)				(%)		
Productive work time (PW)	88.0	85.7	67.7	79.0	76.0	75.1	73.8
Operational preparatory time (OP)	0.0	1.5	5.0	3.0	4.0	8.2	3.3
Planning time (PL)	0.0	1.4	0.8	1.5	0.0		1.5
Ancillary work time (AW)	0.0	0.8	2.2	2.0	2.0	8.2	0.9
Maintenance time (MT)	0.0	5.3	4.4	4.2	5.0		5.5
Repair time (RT)	1.7	0.4	4.3	0.6	5.0		2.0
Meal +Rest and personal time (ME+ RP)	4.5	3.8	9.9	5.1	5.0	8.2	6.6
Interference time (IT)	4.1	0.0	4.6	0.4	0.0	0.0	2.6
Disturbance time (DT)	1.7	1.0	1.0	4.2	0.0	0.0	2.4
Other	-	-	-	-	2.0	-	1.3

3.2 Shift time analysis

Table 3 shows the share of the shift times for the four machines monitored in detail. Except for #3 (John Deere 1010E), they all had a higher utilisation rate (ratio of the productive and scheduled machine hours) than the model 76% share of the operating time presented by domestic PSHN standards. In the presented tables, the time designation in brackets gives the time equivalent of the IUFRO nomenclature (Björheden and Thompson 1995). In particular, repairs were periods with a significant difference that explained the higher proportion of the operational time. Repair time accounted for approximately 1.75% of the shift time, ranging from 0.4 to 4.3%. The summary of the descriptive statistics of observed shift times is shown in a standard boxplot format (Fig. 2).

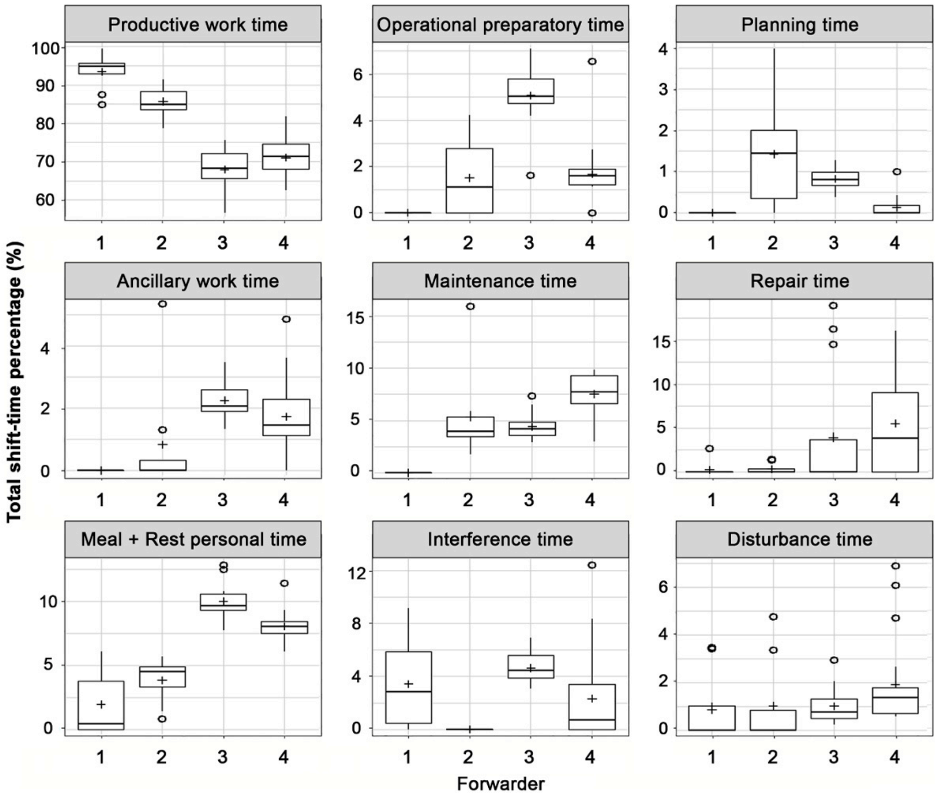

Figure 2: Descriptive statistics of monitored shift-time components in standard boxplot format (box representing 2nd and 3rd quartiles, bar inside box representing median, whiskers extending from the box to minimum and maximum – set as box height multiplied with 1.5 and dots representing outliers beyond the maximum and minimum) with added crosses representing arithmetic mean.

Abbildung 2: Deskriptive Statistik der überwachten Schichtzeitkomponenten im Standard-Boxplot-Format (Box zeigt 2. und 3. Quartil, der Balken innerhalb der Box den Median, Whiskers erstrecken sich von der Box bis zum Minimum und Maximum festgelegt als Boxhöhe mal 1,5 und Punkte sind die Ausreißer jenseits des Maximums und Minimums). Kreuze zeigen das arithmetische Mittel.

Table 4: Basic machine utilisation indicators.

Tabelle 4: Grundindikatoren für die Maschinebenutzung.

Indicator	Machine number			
	1	2	3	4
	(%)			
Mechanical availability rate	98.3	94.3	91.3	95.1
Machine utilisation rate	88.0	85.7	67.7	79.0

The values of the machine utilisation indicators found in this study are given in Table 4. A statistical comparison (Table 5) shows that most observed times differ significantly from PSHN and other authors. The relative and absolute differences are shown in Tables 6 and 7, respectively, apart from the differences in the proportions of the Ancillary work time, which are, in most cases, statistically insignificant. For other authors' models, the differences were more noticeable. For the time proportions, according to Stankic *et al.* (2012), the difference from the measured times was evident, except for one case of Interference times.

Table 5: Paired t-test analysis of shift times in relation to values found or modelled by different authors. Note: A – PSHN (2011); B – Stankić et al. (2012); C – Javůrek and Dvořák (2018).

Tabelle 5: Analyse der ermittelten Schichtanteile verglichen durch den t-Test mit den Modellwerten anderer Autoren. Bemerkung: A – PSHN (2011); B – Stankić *et al.* (2012); C – Javůrek , Dvořák (2018).

	Machine number											
	1			2			3			4		
Shift-time component (IUFRO designation)	mMdel											
	A	B	C	A	B	C	A	B	C	A	B	C
Productive work time (PW)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.000	<0.001	0.025
Operational preparatory time (OP)	<0.001	<0.001	<0.001	0.003	<0.001	0.013	0.004	<0.001	<0.001	0.000	<0.001	<0.001
Planning time (PL)	<0.001	<0.001	<0.001	0.019	<0.001	0.862	<0.001	<0.001	<0.001	0.024	<0.001	<0.001
Ancillary work time (AW)	<0.001	<0.001	<0.001	0.122	<0.001	0.920	0.083	<0.001	<0.001	0.309	<0.001	0.005
Maintenance time (MT)	<0.001	<0.001	<0.001	0.829	<0.001	0.928	0.141	<0.001	0.009	0.000	<0.001	<0.001
Repair time (RT)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.614	<0.001	0.281	0.663	<0.001	0.008
Meal, Rest and personal time (ME + RP)	0.004	<0.001	<0.001	0.105	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Interference time (IT)	0.008	0.008	0.435	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.007	0.728
Disturbance time (DT)	0.086	0.086	0.008	0.178	0.178	0.082	<0.001	<0.001	<0.001	<0.001	<0.001	0.259

Table 6: The relative difference between observed shift time proportions and the proportions used in the standard of PSHN (2011).

Tabelle 6: Relative Unterschiede zwischen den ermittelten Anteilen an Schichtzeiten und von PSHN (2011) gemeldeten Anteilen.

Shift-time component (IUFRO designation)	Relative difference against PSHN (%)			
	Machine number			
	1	2	3	4
Productive work time (PW)	+12.0	+9.7	-8.3	+3.0
Operational preparatory time (OP)	-4.0	-2.5	+1.0	-1.0
Planning time (PL)	+-0.0	+1.4	+0.8	+1.5
Ancillary work time (AW)	-2.0	-1.2	+0.2	+-0.0
Maintenance time (MT)	-5.0	+0.3	-0.6	-0.8
Repair time (RT)	-3.3	-4.6	-0.7	-4.4
Meal +Rest and personal time (ME+ RP)	-0.5	-1.2	+4.9	+0.1
Interference time (IT)	+4.1	+-0.0	+4.6	+0.4
Disturbance time (DT)	+1.7	+1.0	+1.0	+4.2

Table 7: Absolute difference between observed shift time proportions and the proportions used in the standard of PSHN (2011).

Tabelle 7: Absolute Unterschiede zwischen den ermittelten Anteilen an Schichtzeiten und von PSHN (2011) gemeldeten Anteilen.

Shift-time component (IUFRO designation)	Absolute difference against PSHN (minutes)			
	Forwarder			
	1	2	3	4
Productive work time (PW)	+37.7	+62.0	-35.7	+17.9
Operational preparatory time (OP)	-12.6	-15.6	+4.5	-6.2
Planning time (PL)	+-0.0	+8.9	+3.5	+9.0
Ancillary work time (AW)	-6.3	-7.5	+1.0	+0.2
Maintenance time (MT)	-15.8	+2.0	-2.6	-4.6
Repair time (RT)	-10.3	-29.6	-2.9	-25.9
Meal +Rest and personal time (ME+ RP)	-1.6	-7.4	+21.0	+0.4
Interference time (IT)	13.0	0.0	19.7	2.3
Disturbance time (DT)	5.3	6.4	4.2	24.8

4 Discussion

4.1 Overall productivity analysis

In our study, no significant differences between actual and standard productivity of the low power class forwarders (#1 – Vimek 606T and #2 – Novotný LVS 5) seem to indicate that models used in PSHN for this class of forwarders are accurate. PSHNs overestimation of the machine productivity in observed production conditions for #3 (John Deere 1010E) and #4 (Timberjack 810B) could be expected as performance models specific for thinning operation for mid and high power class forwarders do not exist in production conditions similar to those in the Czech Republic. The thinning models are designed only for the low-power class of forwarders (up to 60 kW). Therefore, applying to the machines mentioned above with a higher power is inappropriate. In the case of the Timberjack 810B (#4,), the average load (8.62 m³) was considerably smaller than the one considered by PSHN, *i.e.* 12.1 m³, which could have had a significant effect on performance.

Some studies suggest that PMH productivity remains the same with machine development, and the shift time ratio changes in favour of operating time (Manner *et al.* 2013). This is not the case as there are also significant differences between expected and observed PMH productivity.

4.2 Shift times analysis

Except for the #3 (John Deere 1010E), all studied machines had a higher utilisation rate than the model 76% share of the operating time presented. In the case of #3, the percentage of 67.7% was very close to the shares reported by Nový (2015). This disproportion, in some cases, leads to over-compliance with the standard. A lower proportion of the repair time than PSHN standard 5% does support the repair time rate of 3.7%, respectively 3.1% in clear cuts and thinnings reported by Eriksson and Lindroos (2014). Overall, repair time accounted for approximately 1.75%. As shown by comparison with the study conducted by Javůrek and Dvořák (2018), where the share of repairs was 2%, this could be a systematic change from previously reported findings on which the PSHN standards are based. If machine failures have decreased, either through advances in technology or through a more sensitive approach from operators, it is a fundamental change. This change cannot be explained by more maintenance, where perhaps some problems would be solved and subsequently classified in maintenance, as the proportion of maintenance is approximately the same, in accordance with other authors – *e.g.* (Eriksson and Lindroos 2014) report 4.6-4.9%. However, it should be noted that outputs from the onboard computer were used in the mentioned study, which may not accurately represent reality unless problems are registered. Repairs are carried out when the machine is turned off.

This change in failure rate and needed repairs is also supported by further research; for example, Nordfjell *et al.* (2010) concluded that mechanical availability (MA) had increased substantially in machines since 1985. The average MA approached 80% to 90% by 2008. Similarly, Fiedler *et al.* (2017) reported an MA of 82.5% in 2010 and 82.1% in 2011. The MAs found in this study were even higher. On the other hand, the values of machine utilisation (MU) found in this study are consistent with Ghaffariyanem (2015), who observed MU for Valmet 890.3 (81.1%). However, Holzleitner *et al.* (2011) report an MU of 63% in the long-term study. In a recent long-term study in the Czech republic (Dvořák *et al.* 2021) the MU between 63.3% and 89.3% has been reported.

When comparing the measured times with the selected time distributions from other authors, it can be said that despite significant differences from the measured times, PSHNs still represent the proportions of consumption of shift times closest to the observed times.

For the time proportions, according to Stankic *et al.* (2012), the difference from the measured times was evident, except for one case of Interference times. However, this was to be expected, given other conditions, including labour legislation differences. Indeed, we can see significant differences when compared with other authors, such as Fiedler *et al.* (2017), whose time distribution in a study from Brazil is quite different. However, this can be expected, given the different location legislation and forest type. Another possible reason for the differing findings is the usage of various time nomenclature and their non-compatibility. The times within PSHN measurements are compatible with the IUFRO nomenclature; however, some authors prefer different nomenclature, for example, by dividing the delays into those shorter and longer than 15 minutes and subsequently considering short delays as a part of the work. It is represented by the simplified IUFRO model (Acuna and Heidersdorf 2008), which is not suitable for comparison with other models, like that used in the study of Holzfeind, Stampfer, and Holzleitner (2018), who recommended using a conversion factor to convert between operating time without counting shorter delays and time with delays. However, this makes subsequent comparisons difficult.

5 Conclusions

The data presented in this study showed that the currently used forwarders productivity models are not accurate enough for the tasks they are intended for in the current conditions in the Czech Republic. This deviation consists of the different production conditions for which the models were prepared and the higher proportion of the operational time.

Future productivity standards should consider the different proportion of the shift times in favour of the productive work time and establish a new productivity model for the mid and high-performance class of forwarders. The low power class showed no statistical difference in the PMH productivity.

Both identified problems resulted from difficult quantification and incorporation of the factors affecting them – especially the qualifications and experience of the operator of the forwarder, the failure rate of machines *etc.*, which makes use of models difficult.

As possible solution for some of the issues regarding productivity, we could concentrate our efforts on predicting the productivity of the harvester node, as in the USA (Tufts 1997). Other authors also support this approach (Nurminen *et al.* 2006). In addition, we should separately observe the performance of the forwarding tractors in timber extraction after moto manual logging.

References

Acuna, M., and E. Heidersdorf. 2008. "Draft Technical Report – Harvesting Machine Evaluation Framework for Australia."

Athanassiadis, D, G Lidestav, and I Wästerlund. 1999. "Fuel, Hydraulic Oil and Lubricant Consumption in Swedish Mechanized Harvesting Operations." Journal of Forest Engineering 10 (1): 59–66. https://doi.org/10.1080/08435243.1999.10702725.

Berger, Christiane. 2003. "Mental Stress on Harvester Operators." In Proceedings of the Austro2003 Meeting: High Tech Forest Operations for Mountainous Terrain. CD ROM, edited by Limbeck-Lilienau, Steinmüller, and Karl Stampfer, 10. Schlaegl – Austria.

Björheden, Rolf, and Michael A. Thompson. 1995. "AN INTERNATIONAL NOMENCLATURE FOR FOREST WORK STUDY." In Proceedings of IUFRO 1995, edited by David B Field, 190–2015. Orono, Maine. https://www.nrs.fs.fed.us/pubs/jrnl/2000/nc_2000_Bjorheden_001.pdf.

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

Dvořák, Jiří, Martin Chytrý, Pavel Natov, Jankovský Martin, and Beljan Karlo. 2019. "Long-Term Cost Analysis of Mid-Performance Harvesters in Czech Conditions." Austrian Journal of Forest Science 136 (4): 351–72.

Dvořák, Jiří, Martin Jankovský, Martin Chytrý, Ondřej Nuhlíček, Pavel Natov, Mariusz Kormanek, and Radim Löwe. 2021. "Operational Costs of Mid-Performance Forwarders in Czech Forest Bioeconomy." Forests 12 (4). https://doi.org/10.3390/f12040435.

Eriksson, Mattias, and Ola Lindroos. 2014. "Productivity of Harvesters and Forwarders in CTL Operations in Northern Sweden Based on Large Follow-up Datasets." International Journal of Forest Engineering 25 (3): 179–200. https://doi.org/10.1080/14942119.2014.974309.

Fiedler, Nilton Cesar, Flávio Cipriano De Assis Do Carmo, Luciano José Minette, and Amaury Paulo De Souza. 2017. "Operational Analysis of Forest Harvesting... OPERATIONAL ANALYSIS OF MECHANICAL CUT-TO-LENGTH FOREST HARVESTING SYSTEM 1 ANÁLISE OPERACIONAL DA COLHEITA FLORESTAL EM SISTEMA MECANIZADO DE TORAS CURTAS." Revista Árvore 41 (3): 410301. https://doi.org/10.1590/1806-90882017000300001.

Ghaffariyan, M R. 2015. "Evaluating the Machine Utilisation Rate of Harvester and Forwarder Using On-Board Computers in Southern Tasmania (Australia)." JOURNAL OF FOREST SCIENCE 61 (7): 277–81. https://doi.org/10.17221/21/2015-JFS.

Holzfeind, Thomas, Karl Stampfer, and Franz Holzleitner. 2018. "Productivity, Setup Time and Costs of a Winch-Assisted Forwarder." https://doi.org/10.1080/13416979.2018.1483131.

Holzleitner, Franz, Karl Stampfer, and Rien Visser. 2011. "Utilization Rates and Cost Factors in Timber Harvesting Based on Long-Term Machine." Croatian Journal of Forest Engineering 32 (2): 501–8.

Javůrek, P., and Jiří Dvořák. 2018. "Evaluation of Total Time Consumption in Harvester

Technology Deployment in Conditions of the Forest Sector of the Czech Republic." Journal of Forest Science 64 (1): 33–42. https://doi.org/10.17221/92/2017-JFS.

Jiroušek, R, R Klvač, and A Skoupý. 2007. "Productivity and Costs of the Mechanised Cut-to-Length Wood Harvesting System in Clear-Felling Operations." JOURNAL OF FOREST SCIENCE 53 (10): 476–82. https://www.agriculturejournals.cz/publicFiles/00421.pdf.

Kuitto, P.J., Keskinen S., Lindroos J., Oijala T., Rajamäki J., Räsänen T., and J. Terävä. 1994. Puutavaran Koneellinen Hakkuu Ja Metsäkuljetus. [Mechanized Cutting and Forest Haulage.] English Summary. Metsätehon. Helsinki: Metsäteho.

Laitila, Juha, Antti Asikainen, and Yrjö Nuutinen. 2007. "Forwarding of Whole Trees After Manual and Mechanized Felling Bunching in Pre-Commercial Thinnings." International Journal of Forest Engineering 18 (2): 29–39. https://doi.org/10.1080/14942119.2007.10702548.

Lukáč, Tibor. 2005. Viacoperačné Stroje v Lesnom Hospodárstve [Anglicky]. Zvolen: Technická univerzita vo Zvolene.

Manner, Jussi, Tomas Nordfjell, and Ola Lindroos. 2013. "Effects of the Number of Assortments and Log Concentration on Time Consumption for Forwarding." Silva Fennica 47 (4). https://doi.org/10.14214/sf.1030.

Manner, Jussi, Lauri Palmroth, Tomas Nordfjell, and Ola Lindroos. 2016. "Load Level Forwarding Work Element Analysis Based on Automatic Follow-up Data." Silva Fennica 50 (3). https://doi.org/10.14214/sf.1546.

Me. 2019. "Zpráva o Stavu Lesa a Lesního Hospodářství České Republiky v Roce 2018." Prague: MZe. http://eagri.cz/public/web/file/640937/Zprava_o_stavu_lesa_2018.pdf.

Moskalik, Tadeusz, Stelian Alexandru Borz, Jiří Dvořák, Michal Ferencik, Sotir Glushkov, Peeter Muiste, Andis Lazdiņš, and Oleg Styranivsky. 2017. "Timber Harvesting Methods in Eastern European Countries : A Review." Croatian Journal of Forest Engineering 38 (2): 231–41.

MZe. 2018. "Zpráva o Stavu Lesa a Lesního Hospodářství České Republiky v r.2017." Praha.

Natov, Pavel, and Jíří Dvořák. 2016. Objemový Výrobní Potenciál pro Harvestorovou Technologii v ČR k 31.12.2015 (Specializované Mapy s Odborným Obsahem). Praha: ČZU v Praze.

Neruda, Jindrich, and Jan Valenta. 2003. "Factors of the Efficiency of Harvesters and Forwarders in Logging." In 36th International Symposium on Forestry Mechanisation: "High Tech Forest Operations for Mountainous Terrain," 1–11. Schlaegl – Austria.

Nordfjell, Tomas, Rolf Björheden, Magnus Thor, and Iwan Wästerlund. 2010. "Changes in Technical Performance, Mechanical Availability and Prices of Machines Used in Forest Operations in Sweden from 1985 to 2010." Scandinavian Journal of Forest Research 25 (4): 382–89. https://doi.org/10.1080/02827581.2010.498385.

Nordfjell, Tomas, Emil Öhman, Ola Lindroos, and Bengt Ager. 2019. "The Technical Development of Forwarders in Sweden between 1962 and 2012 and of Sales between 1975 and 2017." International Journal of Forest Engineering 30 (1): 1–13. https://doi.org/10.1080/14942119.2019.1591074.

Nový, Vladislav. 2015. "Racionalizace Práce Vybraných Výrobních Systémů v Těžbě a Dopravě Dříví."

Nurminen, Tuomo, Heikki Korpunen, and Jori Uusitalo. 2006. "Time Consumption Analysis of the Mechanized Cut-to-Length Harvesting System." Silva Fennica 40 (2): 335–63. https://doi.org/10.14214/sf.346.

Proto, Andrea R., Giorgio Macrì, Rien Visser, Hunter Harrill, Diego Russo, and Giuseppe Zimbalatti. 2018. "Factors Affecting Forwarder Productivity." European Journal of Forest Research 137 (2). https://doi.org/10.1007/s10342-017-1088-6.

Stankic, Igor, Tomislav Poršinsky, Željko Tomašić, Ivica Tonkovic, and Marko Frntic. 2012. "Productivity Models for Operational Planning of Timber Forwarding in Croatia." Croatian Journal of Forest Engineering 33 (June): 61–78.

Stankic, Igor, Tomislav Poršinsky, Ivica Tonkovi, and Marko Frnti. 2011. "Development and Implementation of Productivity Norms for Forwarders In." In FORMEC Austria 2011: Pushing the Boundaries with Research and Innovation in Forest Engineering, 1–16. Graz. https://www.formec.org/images/proceedings/2011/formec2011_paper_stankic_etal.pdf.

Svaz zaměstnavatelů dřevozpracujícího průmyslu. 2007. Doporučená Pravidla pro Měření a Třídění Dříví v ČR 2008. Kostelec nad Černými lesy: Lesnická práce s.r.o.

Tufts, Robert A. 1997. "Productivity and Cost of the Ponsse 15-Series, Cut-to-Length Harvesting System in Southern Pine Plantations." Forest Products Journal 47 (10): 39–46.