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Long-term Cost Analysis of Mid-performance Harvesters in Czech Conditions

Langfristige Betriebskostenanalyse bei Harvestern mittlerer Leistung unter tschechischen Bedingungen

Jiří Dvořák[1], Martin Chytrý[2], Pavel Natov[1], Martin Jankovský[1]*, Karlo Beljan[3]

Keywords: *operational costs, productivity, thinning, operational time, efficiency*

Schlüsselbegriffe: *Betriebskosten, Produktivität, Durchforstung, Betriebszeit, Effizienz, Stück-Masse-Gesetz*

Abstract

The harvester technology is increasingly used in Central and Eastern Europe, yet is still costly and thus has be used efficiently. This study focused on the analysis of the development of operational costs of two mid-performance harvesters (JD770D and JD1070D) over a ten-year period, from 2006 to 2017. The costs were aggregated into four categories: depreciation, services, material, and personnel costs) and the costs were analysed annually. The Harvesters were used in thinning under different conditions, which has to be considered when interpreting our results. The mean stem size processed by the JD770D was 0.11 m³ under bark (u.b.) and it harvested 16,793 m³ u.b. per year of timber operating for 3,166 machine hours (MH) per year. The mean costs per m³ u.b. of produced timber ranged from 6.6 to 10.2 €/m³ u.b. The JD1070D was harvesting trees with a mean stem size of 0.29 m³ u.b. and it harvested 26,837 m³ u.b. per year on average, with an operational time of 3,067 MH. The mean costs per

[1] Department of Forestry Technologies and Construction, Faculty of Forestry and Wood Sciences; Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague, Czechia
*Corresponding author: Martin Jankovský, jankovskym@fld.czu.cz
[2] Vojenské lesy a statky, GOE, Pod Juliskou 1621/5, 165 00 Prague, Czechia
[3] Department of Forest Inventory and Management, Faculty of Forestry, University of Zagreb, Svetošimunska 25, 10000 Zagreb, Croatia

cubic meter u.b. of produced timber ranged from 5.4 to 6.9 €/m³ u.b. Personnel costs were important in driving costs and their share at the total operational costs were 40 % for JD770D and 31 % for JD1070D. Material costs were also comparably high with 23 and 28 % of the total operational costs of JD770D and JD1070D, respectively. Depreciation accounted for 18 % and 23 % for the two studied harvesters. The temporal utilization of the harvesters ranged from 63 to 96 %, with higher values for the JD770D. With increasing number of operators, the utilization rate decreased. Given the importance of personnel costs in the studied harvester further analyses should focus on optimizing this decisive driver of costs in mid-performance harvesters in Central Europe.

Zusammenfassung

Die Verwendung von Harvestern (Holzvollerntegeräte) wirt derzeit in Mittel- und Osteuropa immer häufiger, obwohl diese Maschinen hohe Kosten verursachen und deren Nutzung sorgfältig geplant werden muss um effizient zu arbeiten. Ziel dieser Studie ist die Analyse der Betriebskostenentwicklung bei zwei Harvestern mittlerer Leistungsfähigkeit (JD770D and JD1070D) über zehn Jahre von 2006 bis 2017. Die buchhalterischen Kosten wurden in vier Kostenbereiche gegliedert (Abschreibungen, Dienstleistungen, Material und Personalkosten). Die Harvester wurden bei Durchforstungen unter unterschiedlichen Bedingungen eingesetzt und dies muss bei der Interpretation unserer Ergebnisse berückisichtigt werden. Der mittlere geerntete Stammholzdurchmesser des JD770D Harvester betrug 0.11 m³ ohne Rinde (o. R.). Das durchschnittliche Holzernte pro Jahr betrug 16,793 m³ o. R. und die durchschnittliche jährliche Betriebszeit 3,166 Maschinenarbeitsstunden (MAS). Dies ergab durchschnittliche Kosten pro Kubikmeter produziertem Holz zwischen 6.6 und 10.2 €/m³ o. R. Mit dem JD1070D wurden Bäume mit durchschnittlichem Stammdurchmesser von 0.29 m³ o. R. geerntet. Die durchschnittliche Erntemenge betrug 26,837 m³ o. R. bei einer Betriebszeit von 3,067 MAS. Die durchschnittlichen jährlichen Kosten betrugen 5.4-6.9 €/m³ o. R. Der größte Kostenanteil war bei beiden Maschinen die Personalkosten mit 40 % für den JD770D und 31 % für den JD1070D. Der Anteil der Materialkosten war 23 % bzw. 28 %, der Kostenanteil für Dienstleistungen betrug 18 % bzw. 23 %, während die Geräteabschreibungen mit 19 % bzw. 18 % den geringsten Kostenanteil darstellten. Die Nutzungsquote der Harvester lag zwischen 63 und 96 % mit höheren Werten für den JD770D. Je höher die Anzahl der Maschinisten war, umso geringer war die Nutzungsquote der Geräte. Angesichts der klaren Bedeutung des eingesetzten Personals erscheinen weitere Analysen erforderlich, um diesen wichtigen Faktor der Leistungsfähigkeit von Harvestern in Mittel- und Osteuropa weiter zu optimieren.

1. Introduction

The first harvester was deployed in the Czech Republic as early as 1977 to cope with the massive air pollution in the Krušné Hory Mountains at this time (Dvořák et al. 2011). Yet wide-spread use of harvester technology did not happen until the turn of the millennium. The increasingly frequent of this technology was caused by many factors, including a shortage of skilled forest workers, increasing personnel costs and/or an increasing ratio of incidental felling (often caused by wind throw and bark beetles) asking for immediate and fast action. Since then the market share of harvesters has been increasing rapidly (Dvořák et al. 2018, MZe 2017) and over ten years, almost one third of all harvests were conducted by harvesters (Fig. 1).

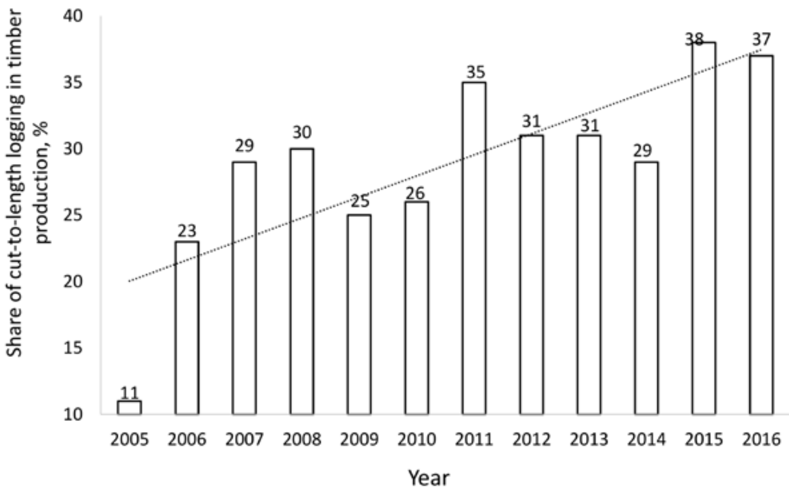

Figure 1: Share of cut-to-length logging in timber production in Czech Republic in 2005-2016 (Source: Ministry of Agriculture of the Czech Republic).

Abbildung 1: Anteil Sortimentverfahren in der Holzeinschlags der Tschechischen Republik von 2005 bis 2016 (Quelle: Ministry of Agriculture of the Czech Republic).

A similar boom in harvester technology can be seen throughout the Central and Eastern European or the Baltic regions. For instance in Estonia harvesters account for 95 % share in final cuts or in Latvia for about 70 % of all harvested timber, while in lower income countries such as Ukraine or Bulgaria, harvesters are still not very popular and rarely used (Moskalik et al. 2017). There are several reasons for the different share of harvester-based systems on the total harvested volume in certain countries that are connected (but not limited) to economics. Harvester usage often incurs higher operational costs and their purchase presents higher initial capital expenses compared to conventional technologies, which limits their use in regions where timber producers are faced with limited capital.

Besides favourable economic conditions, the increasing share of harvester technology in Czech Republic can be partially attributed to the good production conditions. According to Czech terrain classification (ÚHUL 2007), harvester technology is recommended for use in slopes up to 40 %. The recommended height of obstacles must not exceed 50 cm and the machines should not be deployed in stands with permanently or temporarily impaired load bearing capacity. Terrain classification allows harvester and forwarder deployment in terrains able to bear at least 50 kPa of nominal ground pressure (Simanov et al. 1993, ÚHUL 2007).

Stands composed of at least 80 % coniferous species as well as stands dominated by birch or beech up to 50 years of age are considered suitable for harvester technology. Long-term research demonstrated that harvester technology can be efficiently used even in stands with a low mean stem size of 0.05 m³ u.b. (Dvořák et al. 2011). In Czech Republic, about 72 % of all forests meet the above criteria for efficient harvester technology use (Dvořák and Natov 2016). Depending on the region, the share of forest land suitable for harvester systems ranges from 49 to 79 % of the total forest area (Dvořák et al. 2018). Selecting an appropriate machine and its place of deployment is therefore key in achieving high productivity at minimal costs.

Productivity analysis is frequently used as first step in economic analyses using data related to production units (cubic metres under bark; m³ u.b.). Productivity is affected by a number of factors, particularly the mean stem size, harvesting intensity, tree species, type of harvest, produced assortments, the performance class of the given harvester, and/or the human factor (Mederski et al. 2016, Dvořák et al. 2015, Dvořák et al. 2011, Schlaghamerský 1994, Nouzová 1988, Visser and Spinelli, 2012). Each of the factors listed above affects productivity to a different extent. When setting performance standards, researchers seek to determine machine (or technology) productivity with respect to the mean stem size (Wöll-Jónsson 2009, Jiroušek et al. 2007,) or mean diameter at breast height of the harvested trees (Baek et al. 2008, Kellogg and Bettinger 1994), which obviously relates to mean stem size. Interestingly, the number of produced assortment classes is rarely considered as driver of productivity. Yet research indicate that every additional assortment class put into the machine system decreases productivity by 1 % in thinnings (Sirén and Aaltio 2003).

The direct costs of harvesting machinery can be divided into personnel, material (fuel, lubricants, tyres, etc.), services (repairs and maintenance), and depreciation. According to the representatives of Vojenské lesy a statky, GOE, who operate several harvesters, personnel costs constitute the largest share of the total direct costs and range typically between 16 and 30 % of the total costs. The next most important cost type are material costs ranging from 15 to 28 %, where fuel and lubricants contribute most (6 - 17 %). Total costs depend on the price level of labour, material, and services, as well as the legislation in a particular country. Total costs also contain overheads and other indirect costs, which are highly variable and depend on the organizational structure and other internal factors of the company that operates the machines. For this reason, we omitted analysing indirect costs in this study.

Regarding the type of harvest, the productivity is smallest in early thinnings (10.3 m^3 u.b./h), increases in later thinnings up to 27.7 m^3 u.b./h and is highest in clear cuts of up to 33.2 m^3 u.b./h. Incidental fellings have a lower productivity of up to 11.9 m^3 u.b./h, depending on the stem size, stand density, tree species, and the terrain factors, as listed above (Dvořák et al. 2011, Baek et al. 2008, Mizaras et al. 2008, Kärhä et al. 2004, Sirén and Aaltio 2003, Kellogg and Bettinger 1994).

To ensure return on investment, harvesters need to be efficiently utilized. The mean published operational time (gross-effective time including delays < 15 min) ranges from 2,361 to 3,120 h/year (Dvořák et al. 2011, Holzleitner et al. 2011, Nurminen et al. 2009).

Nevertheless, the human factor remains key. For instance, the productivity of different operators on identical machines may vary by up to 40 % (Kärhä et al. 2004). Moreover, productivity does not differ only due to the given type of felling, but is considerably influenced by techniques and practices as well (Malinen et al. 2018, Dvořák et al. 2016).

With increasing productivity, production costs per m^3 u.b. decrease (Mizaras et al. 2008). Machines with lower investment and production costs per m^3 u.b. may be one efficient solution for early thinnings (Sirén and Aaltio 2003). Though certain analyses, mostly case studies conducted in selected stands and on individual machines, report production costs in relation to m^3 u.b. of timber, most cost analyses relate productivity to the mean stem size or the harvested volume per hectare. Very different costs are presented with respect to individual countries. On the other hand, thinning costs ranging from 4 to 12 €/m^3 u.b. were reported by Petaja et al. (2017), Nurminen et al. (2009), Sirén and Aaltio (2003) and Kellogg and Bettinger (1994). Practically the same cost range (4 to 12 €/m^3 u.b.) was reported by Nurminen et al. (2009) or Kärhä et al. (2004) for final cuts.

As previously mentioned production costs also change in relation to the produced assortments. Although the effects of the number of assortment classes on machine productivity is rather small, production costs of shorter logs (pulp wood) are consistently higher than those of longer logs (Nurminen et al. 2009).

This study focused on analysing the difference of direct operational costs of two harvesters (JD770D and JD1070D) at the opposite ends of the mid-performance class (70–140 kW). We hypothesized that the difference in direct operational costs of the machines is not statistically significant. We also wanted to analyse the long-term costs of operating the two harvesters in the conditions of Czech forestry. We hypothesized further that the increase of nominal direct operational costs was high for both machines.

2. Material and Methods

2.1 Details on studied machines

Our study focussed on the direct operational costs of two harvesters operated by Vojenské lesy a statky, GOE (VLS), in its Hořovice division. The harvesters were used purely in the VLS owned forests. The Hořovice division, situated in Jince, manages 28,000 ha of forest (Fig. 2).

Figure 2: Location of deployment zone of the harvesters, the Hořovice Division, Vojenské lesy a statky, GOE, in the Czech Republic.

Abbildung 2: Lage des Einsatzgebietes der zwei Harvester, Hořovice Division, Vojenské lesy a statky, GOE, in der Tschechischen Republik.

In total, the six divisions of VLS manage 126,000 ha of forest. The harvesters were deployed in a way that their work sites were close by, to reduce transfer times. Often allowed self-propelled transfer of the machines between the work sites was possible.

Both harvesters were newly purchased by VLS. John Deere 770 harvester (JD770) operated from 2008 to 2017 and the John Deere 1070 harvester (JD1070) operated from 2006 to 2014 (Table 1).

Table 1: Harvester operational and capital expenses data.

Tabelle 1: Details zu Anschaffung und Verkauf der Harvester.

Model	Date of purchase	Purchase price	Date of sale	Selling price
	(month/year)	(€)	(month/year)	(€)*
John Deere 770	10/2007	263,000	8/2018	24 725
John Deere 1070	4/2004	284,000	5/2015	23 388

*Exchange rates: 25.683 CZK/€ (8/2018); 27.936 CZK/€ (5/2015)

JD1070 had a performance corresponding to the upper limit of the mid-performance class and JD770 to its lower limit. For more detailed information on the machines, see Table 2.

Table 2: Machine technical information.

Tabelle 2: Technische Informationen der Harvester.

		John Deere 770D	John Deere 1070D
Base machine	Mass (kg)	11,550	14,100
	Width (m)	2.40	2.79
	Intended mean stem size of processed trees (m^3 u.b.)	0.11	0.29
Engine	Type	John Deere 4045 HTJ	John Deere 6068 HTJ
	Performance (kW)	86	129
Transmission		hydrostatic-mechanical	
Boom	Type	140H	180S
	Reach (m)	9.7	9.7
Harvester head	Type	H742/745	H742/745/752/754
	Maximum tree diameter (cm)	45	55

2.2 Environmental conditions

The machines worked in forests of the Brdy massif, located in the south-western part of central Bohemia. The terrain had highland character, with elevation ranging from 420 to 865 metres above sea level. Mean annual precipitation was 650–800 mm and the mean temperature was 7 °C. Tree species composition was favourable for harvester deployment, with 67 % of Norway spruce (*Picea abies*), 14 % of Scots pine (*Pinus sylvestris*) and 8 % of European larch (*Larix decidua*). On total, 71 - 80 % of the area had favourable conditions for the deployment of harvesters outlined in the introduction, with suitable slope, up to 50 %, high soil bearing capacity, no obstacles, coniferous, with a mean stem size ranging from 0.05 to 1 m^3 u.b.

2.3 Cost structure

The cost reporting structure was the same for both machines. No methodical changes in accounting were made throughout the observed period. For analytical purposes, the detailed costs on record were broken down and aggregated into four cost groups based on their type (ČESKO 2002), (i) Depreciation, (ii) Services, (iii) Material and (iv) Personnel costs.

(i) Depreciation included the share of the purchase price of the machine, as well as the share of purchase price of other assets related to the operation of that machine eligible as costs per year. Depreciation also included materials such as electronic callipers for calibrations and control measurements of the harvester or a chain grinder. Czech legislation recognizes either linear or accelerated depreciation methods. Both machines were depreciated linearly. However, the respective depreciation rates differed due to a change in legislation between the purchase of JD1070 and JD770.
(ii) Services included mainly maintenance and repairs, which were combined, as they could not be considered separately. Repairs, refills of hydraulic oil, and replacement of spare parts were carried out simultaneously with periodic inspections of the machines. Similarly, operational adjustments were often carried out together with repairs.
(iii) Material costs were mostly expenses for fuel, tyres, and lubricants.
(iv) Personnel costs included salary, social and health insurance, as well as other items directly related to human resources, such as travel expenses, road tax, work clothes and other protective gear, its cleaning and maintenance, medical services, accident insurance, liability insurance, retirement co-pay benefits, cell phone costs, training and education.

Taxes and fees, other costs, financial costs, transfer costs, costs were considered overheads and as such were not subject of our analysis. The reason why we did not consider overheads was that they do not directly depend on the working conditions of the harvesters, but rather on the policies of the company or legislation in a given country and therefore would be difficult to compare across countries or regions.

The costs were recorded in Czech crowns. To be comparable with results of other studies, the costs were converted into Euro using the mean annual exchange rate (Fig. 3).

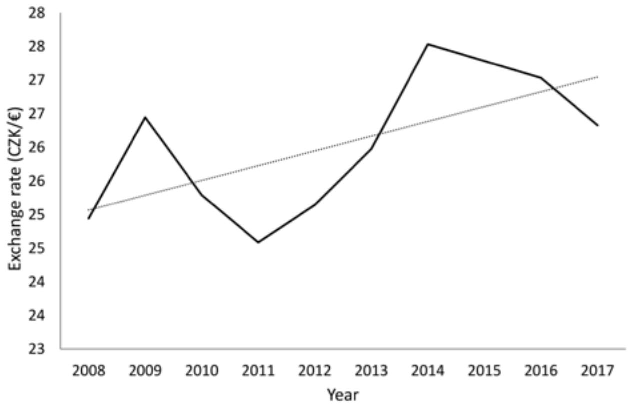

Figure 3: Mean annual exchange rate (CZK/€).

Abbildung 3: Durchschnittlicher jährlicher Wechselkurs (CZK/€).

Within the observed period, Czech crown was artificially weakened by the Czech National Bank to maintain a stable exchange rate to Euro. This intervention partially dampened inflationary pressures during the period. The development of costs for each machine and cost types was rendered for the entire calendar years within the observed period. As a result, the mean annual inflation rate varied from 0.3 % (2015) to 6.3 % (2008) (Fig. 4).

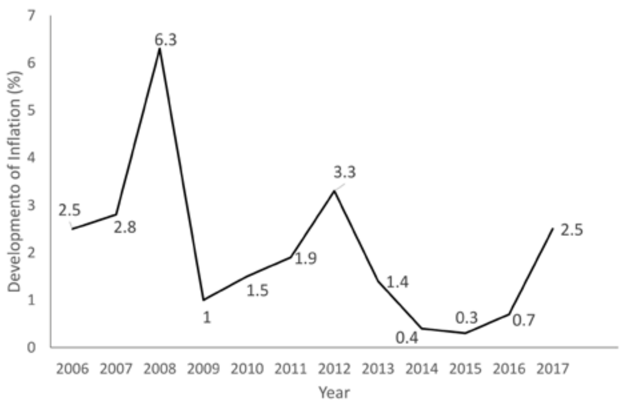

Figure 4: Annual inflation rate in the Czech Republic throughout the observed period.

Abbildung 4: Jährliche Inflationsrate in Prozent in der Tschechischen Republik während des Untersuchungszeitraums.

All costs were considered in their nominal values and were not adjusted to present value.

The analysis focused on annual costs when the harvesters operated continuously for 12 months. Apart from costs, performance was monitored in terms of temporal units (operational time in machine hours – MH, delays in scheduled machine hours – SMH) and production units (m^3 u.b.).

2.4 Data analyses

Temporal utilization was calculated as the share of operational hours on the scheduled annual working time. The formula was as follows:

$$TU = \frac{OT}{(OT+DT)} * 100 \quad (1)$$

Where: TU is the temporal utilization (%); OT the operational time of the machines (MH); DT the downtime, i.e. time, when the machines were not operational during working time due to repairs, maintenance or other reasons (SMH).

Productivity of the machines was calculated as the number of produced m^3 u.b. per MH.

The statistical analysis examined possible statistically significant differences between the total costs of both machines. Since both data sets were from two machines, we used an unpaired t-test.

3. Results

The obtained aggregated data are shown as tables, presented as Appendices 1–4. Operational data indicated that the JD770 machine was used predominantly in thinnings or tendings. The mean size of the stems harvested by this machine was 0.11 m^3 u.b., mean annual cut was 16,793 m^3 u.b. and mean annual operational time was 3,166 MH (total operational time of the machine during the whole observed period was 32,189 MH). The mean machine productivity ranged from 4.6 to 5.8 m^3 u.b./MH (Appendix 1). The JD1070 harvester was also primarily used for thinnings. It harvested trees with a stem size of 0.29 m^3 u.b. and the mean annual cut was 26,837 m^3 u.b., reaching a similar operational time as JD770 of 3,067 MH (total operational time of the machine during the whole observed period was 28 110 MH). The mean machine productivity ranged from 8.3 to 9.9 m^3 u.b./MH (Appendix 3).

The operator plays a key role in reaching and maintaining efficient harvester operation. This is demonstrated by the temporal utilization of the machines. The mean temporal utilization rate of the JD770 over the monitored period was 89.2 %, whereas in the worst year, 2013, it was 80.9 %. Two regular operators took turns in operating the smaller machine. The utilization rate of the JD1070 machine was substantially lower, about 70 %. The lower utilization was likely caused by the more frequent operator changes throughout the observed period. Furthermore, more operational modes were tested by VLS on JD1070. At the time of its launch in 2004, four operators worked the machine in four shifts 24 hours a day. This mode did not prove successful, thus the number of operators gradually decreased to two after 2008. In its last year of deployment, a single operator worked with JD1070. Primarily due to operator approach, the mean time utilization of the machine over the monitored period was only 69.4 % (83 % in the best year 2012).

3.1 Depreciation

The depreciation of harvesters and other assets is directly related to their purchase price and the depreciation rate. The JD1070 was depreciated over the course of eight years, while JD770 was depreciated over the course of five years. Due to this administrative intervention, both machines were written-off in the same year in 2012. After the entire purchase price has been written-off, no other accounting costs were reported, and depreciation amounted to zero. That is why Fig. 5 and 6 show a decreasing trend of depreciation for both machines. The share of depreciation on the total costs ranged between 18 and 19 % of the total costs. The hourly direct depreciation costs were 9.9 € in JD1070 and 8.5 € in JD770.

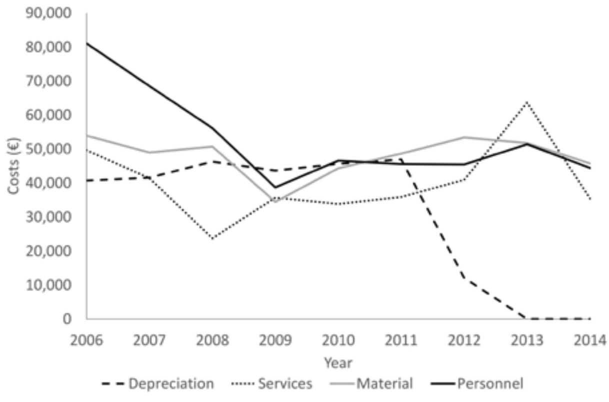

Figure 5: Mean annual direct operational costs of the JD1070 harvester according to cost type.

Abbildung 5: Mittlere jährliche Betriebskosten des JD1070 harvester unterteilt nach Kostentyp.

Figure 6: Mean annual direct operational costs of the JD770 harvester according to cost type.

Abbildung 6: Mittlere jährliche Betriebskosten des JD770 harvester unterteilt nach Kostentyp.

3.3 Material costs

Fuel costs were relativly stable and did not change over the course of machine operation. They were affected, however, by the market prices of diesel or lubricants and the temporal utilization of the machine in the given year (Fig. 5 and 6).

The share of fuel costs on the total costs was 22 % for JD770 and 28 % for JD1070. The mean fuel costs per MH for JD770 were 10.0 €, for JD1070 they were 15.4 €. The higher consumption of JD1070 was due to the higher performance of its engine.

The costs of tyre repairs and replacement are marginal compared to total costs. However, they often get overrated and thus were given a specific place in the cost breakdown. If they fluctuate near zero, they represent only tyre repairs. Increased costs in a given year indicate purchase of new tyres. In JD770 all four tyres were replaced in 2012, after its depreciation. The tyres of JD1070 were replaced separately for each axle, i.e. in three instances. The share of tyre costs in the total costs both for JD770 and JD1070 was 1 %. The mean tyre repair and replacement costs per MH for JD770 were 0.3 €, for JD1070 they were 0.4 €.

3.4 Personnel costs

Personnel costs (Fig. 5 and 6) are critical for harvester operation. Efficient operators, who work well with the machine, perform machine maintenance regularly and responsibly, and deal with potential defects in advance not only decrease the operational and repair costs but achieve a higher temporal utilization of the machine by eliminating delays. With higher machine performance, the profitability of the whole harvester management unit increased, which in turn reflected the increased operator's wage.

The reported share of personnel costs on the total costs for JD770 was 40 %; for JD1070 it was 31 %. The mean personnel costs per MH for JD770 were 18.4 €, for JD1070 they were 17.0 €.

3.5 Costs per production unit

Mean stem size is a decisive factor in the cost per production unit, i.e. per m³ u.b. of timber harvested. Due to the different sizes of the studied harvesters, there were differences in the mean stem sizes harvested by the particular machine.

Fig. 7 contains two clearly defined data groups. JD770 from the lower margin of the mid-performance class harvesters, harvested trees with mean stem size of 0.11 m³ u.b primarily in early thinnings in stands aged up to 40 years.

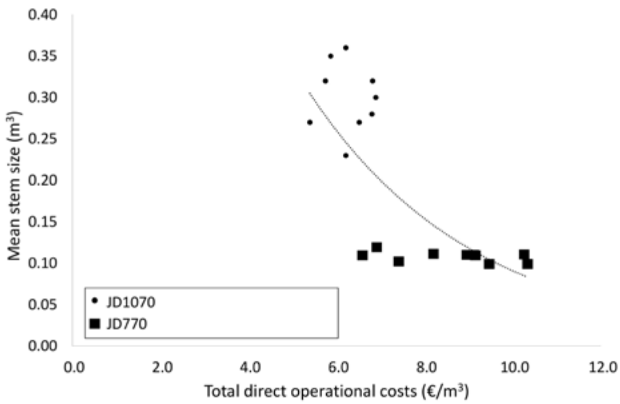

Figure 7: Relationship between the total direct operational costs per harvested m³ under bark of timber on the mean stem size of harvested trees.

Abbildung 7: Zusammenhang zwischen Gesamtbetriebskosten pro m³ ohne Rinde und mittlerem Stammdurchmesser.

Fig. 8 highlights the effects stem size has on the total direct operational costs. The smaller JD770 achieved costs per unit of produced timber in a range of 6.6 to 10.2 €/m³ u.b. In contrast, the JD1070 from the upper margin of the mid-performance class harvesters, harvested primarily in older stands with a mean stem size of 0.29 m³ u.b. and achieved relatively stable costs per production unit of 5.4 to 6.9 €/m³ u.b.

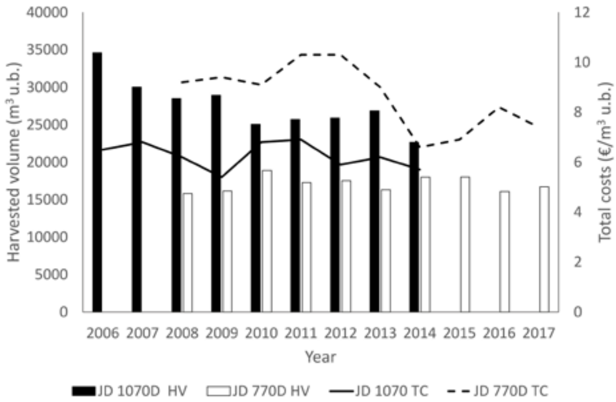

Figure 8: Annual volume of harvested timber volume (HV, unit m³ under bark) and total costs per production units (TC, unit € per m³ under bark) of the John Deere 1070 and John Deere 770 harvesters.

Abbildung 8: Jährliche Erntemenge (HV) in m³ unter Rinde und Betriebskosten pro Produktionseinheit (TC) in € pro m³ unter Rinde des John Deere 1070 und John Deere 770 harvesters.

The unpaired t-test was performed for years when both machines were in operation. The analysis was therefore based on seven repetitions. The test showed no significant differences between the total direct operational costs of the two differently sized machines (p = 0.494). Since the *p* value exceeded the 0.05 significance threshold, we concluded that the distribution of total direct operational costs of both machines did not differ. Furthermore, the mean annual operational costs of the JD770 harvester were 156,043 € (standard deviation – SD = 22,212 €), while the JD1070 reached an average of 161,332 € (SD = 16,823 €). We thus could confirm the hypothesis that there is no statistically significant difference between the total direct operational costs of both machines and that engine power does not affect the operational costs within the 70-140 kW power class.

4. Discussion

Cost analysis of two harvesters on the different ends of the mid-performance class confirmed that personnel costs were the decisive direct cost type (Tab. 3).

Table 3: Costs per harvester machine hour.

Tabelle 3: Harvesterbetriebskosten pro Maschinenstunde unterteilt nach Kostentyp.

Cost item	Harvester model			
	JD770		JD1070	
	(€/MH)	(%)	(€/MH)	(%)
Depreciation	8.5	18.6	9.9	17.8
Services	8.5	18.5	12.8	23.1
Consumed purchases (fuel, tyres)	10.3	22.7	15.8	28.5
Personnel costs	18.4	40.3	17.0	30.7
Total	**45.7**	**100.0**	**55.5**	**100.0**

They represented 31 to 40 % of the total direct operational costs. The better the operators were, the better was the time utilization of harvesters, operational costs, and higher the share of personnel costs. Total personnel costs were 17.0 - 18.4 €/MH. Jiroušek et al. (2007) report an mean hourly rate of 12 €/h. Di Fulvio et al. (2017) estimate that personnel costs, including employers' contributions and other fees (meal allowance, accommodation, personal protective equipment, transport, insurance, training, phone, etc.) range from 7 to 21 €/SMH globally.

The second most significant cost type were fuel costs. They were stable, ranging from 22.0 to 27.7 %, and depended on the technical parameters of a particular machine, as well as the fluctuations of the diesel prices. Costs of fuel consumption stood per hour was 10.0 to 15.4 €/MH. This corresponds to figures reported by Holzleitner et al. (2011), who reported a mean consumption of 15.6 litres per productive machine hour (l/PMH_{15}), or 13.0 €/PMH_{15}.

Costs of services were influenced by two key factors – operator quality and machine age. With increasing machine age, harvester repair costs in particular go up. On the other hand, high quality operators, who perform regular inspections, identify potential problems early on, can therefore substantially decrease the services costs. Services costs ranged from 18.5 to 23.1 % of the total costs, i.e. 8.5 - 12.8 €/MH. Nurminen et al. (2009) and Väätäinen et al. (2006) estimate the costs for repairs and maintenance of a mid-performance harvester at 9.66 €/h. Holzleitner et al. (2011), who analysed 12 machines, quantified the mean repair costs at 20.2 €/PMH_{15}.

Depreciation depends primarily on the purchase price of a harvester and the legislation in a particular country. In our case, the purchase price was 284,000 € (2004) and 263,000 € (2007) respectively. Considering the mean inflation rate in the period of

2004 to 2007 was 2.5 %, the purchase price of the JD770 harvester was 290,303 € in 2004 prices. At present, harvester purchase prices range from 165,000 € to 577,000 €, based on the selected make, performance class, weight, and other specifications (Di Fulvio et al. 2017). Depreciation costs were fixed and as such, they changed only in relation to temporal or production units. The share of depreciation in the total costs per machine hour was approx. 18 %. This cost type can be substantially decreased if a company that manages at least 1,000 ha of forests, takes advantage of the subsidies of the Czech Republic to refund 50 % of the purchase price of harvesters or forwarders with engine power up to 120 kW.

The analyses we conducted proved the well-known fact that man is the key factor in almost any activity. The professionality of the operators determine the time utilization of machines. With decreased delays, operational costs per hour decreased as well. It is therefore important to properly value the work of skilled operators, as these can bring financial benefits to their employers.

The total direct operational costs of the observed mid-performance harvesters were 5.4 - 10.2 €/m³ u.b., depending on the mean stem size of the harvested trees, ranging from 0.11 to 0.29 m³ u.b. Machine utilization influenced the production costs as well. With increasing MH, operational costs per MH decreased (driven by the decreasing depreciation costs per temporal unit), in accordance with other authors, listed above. The mean annual machine utilization revealed by our study was 3,166 MH and 3,067 MH respectively, depending on the machine. Compared to other workplaces, the temporal utilization of the studied machines was relatively high, as the numbers of MH reported by other authors range from 1,439 to 3,120 (Spinelli et al. 2011, Holzleitner et al. 2011), with the total costs of 65.89 to 183.25 €/PMH (Di Fulvio et al. 2017).

One can see that the total costs reported by e.g. Di Fulvio et al (2017) differ substantially from the figures reported in this study. The reason for that lies in the design of our study, since we focused only on the direct operational costs of harvesters, when in fact, indirect costs can also substantially increase the total costs of machine operation (the reasons why we omitted them can be found above in the text). Furthermore, the presented study is largely explanatory, as the aggregated annual data based on two machines provided limited potential for generalization and predictions. In future research, we would like to build upon the lessons learned here and focus more on predictive studies in this field, possibly updating the Czech Forestry Standards (Nouzová, 1988). One potential route is to work with more detailed datasets that bring together several types of data, to find predictors of machine productivity and cost-efficiency, such as weather, terrain, operator-specific characteristics, tree species, stem size, measures taken by the company in preparation for the forest harvesting, etc. Comparison of such data with more detailed costs of operation data would enable the creation of robust predictive models. In turn, these models would benefit the professional public, who would be able to plan the purchase, operation, and termination of their machines more securely.

5. Conclusions

The Hořovice Division of VLS operated their own harvesters exclusively in forests they managed. There is a small number of such entities in the Czech Republic (Forests of the Czech Republic, GOE, VLS, GOE, and several private companies). In such a case, the production investment costs can be significantly reduced by good management practices.

In terms of investment economics, good management practices start before the purchase of a machine or device. Company management should investigate meticulously, what type of machine is best suited for their conditions, as proven by this case study. As it turns out, hourly direct operational costs of both studied machines were similar. Thus, machines on both sides of the mid-performance class can be considered economical in the conditions presented in this study. There are, however, other conditions that must be taken into account when purchasing machinery, be it operational characteristics (e.g. adequate cutting diameter of the harvester head, boom reach, dimensions of the machine, etc.) or environmental factors (e.g. nominal ground pressure, type of chassis, ergonomics, etc.).

This study was focused on observing the direct operational costs of two machines on the opposite sides of the mid-performance class. Although we captured a relatively long time frame, one must consider the limits of such a study: the number of machines included in our study, the fact that we only focused on the direct operational costs of the machines, or the legal and economic framework, in which we conducted the study.

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Appendix

Items	Year										Total	Monthly	Annually	Percentage of expenses
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017				
Depreciation (€)	56,838	53,607	56,056	57,661	46,984	0	0	0	692	1,422	273,260	2,240	26,878	19
Services (€)	16,151	18,126	15,693	23,112	19,891	44,413	26,801	38,868	35,652	33,384	272,090	2,230	26,763	18
Material (€)	32,913	27,919	34,121	39,001	49,048	31,895	33,511	26,895	28,536	29,762	333,600	2,735	32,813	23
Personnel costs (€)	39 264	52 796	66 373	57 457	64 721	69 825	58 124	58 399	66 498	60 032	593 490	4,865	58,376	40
Total (€)	145,165	152,450	172,243	177,230	180,644	146,133	118,436	124,162	131,378	124,600	1,472,440	12,069	144,830	100
Harvested capacity (m^3 u.b.)	15,804	16,142	18,883	17,271	17,525	16,298	17,990	18,010	16,073	16,728	170,724	1,399	16,793	X
Operation time (MH)	3,269	3,497	3,426	3,383	3,152	2,913	3,149	3,092	3,379	2,929	32,189	264	3,166	X
Downtime (h)	361	133	204	217	478	687	451	508	221	656	3,916	32	385	X
Machine utilization (%)	90.1	96.3	94.4	94.0	86.8	80.9	87.5	85.9	93.9	81.7	89.2	X	X	X
Costs (€/m^3 u.b.)	9.2	9.4	9.1	10.3	10.3	9.0	6.6	6.9	8.2	7.4	8.6	X	X	X
Costs (€/MH)	44	44	50	52	57	50	38	40	39	43	46	X	X	X
Output (m^3 u.b./MH)	4.8	4.6	5.5	5.1	5.6	5.6	5.7	5.8	4.8	5.7	5.3	X	X	X
Mean stem size (m^3 u.b.)	0.11	0.10	0.11	0.11	0.10	0.11	0.11	0.12	0.11	0.10	0.11	X	X	X

Appendix 1: Overview of production and direct operational costs of harvester John Deere 770D.

Anhang 1: Übersicht der Produktivität und Betriebskosten des John Deere 770D Harvesters.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Depreciation (€/MH)	17.4	15.3	16.4	17.0	14.9	0.0	0.0	0.0	0.2	0.5	8.5
Services (€/MH)	4.9	5.2	4.6	6.8	6.3	15.2	8.5	12.6	10.6	11.4	8.5
Material (€/MH)	10.1	8.0	10.0	11.5	15.6	10.9	10.6	8.7	8.4	10.2	10.3
Personnel costs (€/MH)	12.0	15.1	19.4	17.0	20.5	24.0	18.5	18.9	19.7	20.5	18.4
Total (€/MH)	44.4	43.6	50.3	52.4	57.3	50.2	37.6	40.2	38.9	42.5	45.7

Appendix 2: Direct operational costs (€/MH) of harvester John Deere 770.

Anhang 2: Betriebskosten pro Maschinenstunde (€/MH) des John Deere 770 Harvesters.

Items	Year									Total	Monthly	Annually	Percentage of expenses
	2006	2007	2008	2009	2010	2011	2012	2013	2014				
Depreciation (€)	40,742	41,595	46,297	43,666	45,660	46,968	12,071	0	0	276,999	2,495	29,946	18
Services (€)	49,647	41,454	23,752	35,709	33,853	35,880	40,960	63,642	35,459	360,355	3,246	38,957	23
Material (€)	53,937	52,985	50,722	37,944	44,337	48,646	53,408	51,756	50,186	443,922	3,909	47,992	29
Personnel costs (€)	81,093	68,543	56,162	38,718	46,606	45,607	45,465	51,402	44,449	478,045	4,307	51,681	31
Total (€)	225,419	204,577	176,934	156,037	170,457	177,101	151,903	166,800	130,093	1,559,322	14,048	168,575	100
Harvested volume (m^3 u.b.)	34,604	30,014	28,495	28,940	25,061	25,708	25,900	26,868	22,648	248,239	2,236	26,837	X
Operation time (MH)	3,896	3,622	3,378	2,919	2,846	2,878	3,003	2,930	2,638	28,110	256	3,067	X
Downtime (h)	2,072	2,160	1,054	970	1,630	979	617	1,656	1,239	12,377	113	1,350	X
Machine utilization (%)	65.3	62.6	76.2	75.1	63.6	74.6	83.0	63.9	68.0	69.4	X	X	X
Total costs (€/m^3 u.b.)	6.5	6.8	6.2	5.4	6.8	6.9	5.9	6.2	5.7	6.3	X	X	X
Total costs (€/MH)	58	56	52	53	60	62	51	57	49	55	X	X	X
Productivity (m^3 u.b./MH)	8.9	8.3	8.4	9.9	8.8	8.9	8.6	9.2	8.6	8.8	X	X	X
Mean stem size (m^3 u.b.)	0.27	0.32	0.23	0.27	0.28	0.30	0.35	0.36	0.32	0.29	X	X	X

Appendix 3: Overview of production and direct operational costs of harvester John Deere 1070.

Anhang 3: Übersicht der Produktivität und Betriebskosten des John Deere 1070 Harvesters.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	Mean
Depreciation (€/MH)	10.5	11.5	13.7	15.0	16.0	16.3	4.0	0.0	0.0	9.9
Services (€/MH)	12.7	11.4	7.0	12.2	11.9	12.5	13.6	21.7	13.4	12.8
Material (€/MH)	14.6	14.6	15.0	13.0	15.6	16.9	17.8	17.7	19.0	15.8
Personnel costs (€/MH)	20.8	18.9	16.6	13.3	16.4	15.8	15.1	17.5	16.8	17.0
Total (€/MH)	57.9	56.5	52.4	53.5	59.9	61.5	50.6	56.9	49.3	55.5

Appendix 4: Direct operational costs of harvester JD1070 (€/MH).

Anhang 4: Betriebskosten pro Maschinenstunde (€/MH) des JD1070 Harvesters.