Article

Operational Costs of Mid-Performance Forwarders in Czech Forest Bioeconomy

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Abstract: Cut-to-length (CTL) operations are expanding in Central European bio-economies. However, they are costly, so efficiency must be maximized. The objective of this study was to analyze direct operational costs of three forwarders from the year 2006 until 2019. Annual amortization, services, materials, and personnel costs were analyzed and compared through ANOVA, trends were analyzed through linear regression. Forwarders LVS 5, John Deere 1010, and John Deere 1110E were deployed in coniferous forest stands with a mean stem volume between 0.10 and 0.84 m^3/stem, forwarding distance between 261 and 560 m. The machines forwarded between 4045 and 34,604 m^3 of timber per year, over operational times between 490 and 3896 MH (machine hours)/year, reaching machine utilization between 58% and 89%, machine productivity between 3.5 and 12.3 m^3/MH, and costs between 20.95 and 84.39 €/MH. The most substantial were personnel costs (35 to 66% of the total costs), followed by materials (14.9–27.1%), amortization (12.5–15.7%), and services (3.3–22.1%). Differences between total operational costs per m^3 of machines with different engine powers were not observed.

Keywords: CTL harvesting; amortization; personnel costs; material costs; repairs and maintenance; productivity

1. Introduction

The first forwarders (e.g., Volvo BM 971) were used in Czechia during the year of 1977. They tackled the pollution disturbances in Krušné hory [1]. However, the expansion of forwarders to the position of one of the main machines used in timber extraction came at the end of the millennium. Several factors contributed to this, from the decrease of the availability of qualified personnel for forest operations, increasing personnel costs, to the increasing share of incidental felling. These, and other, reasons lead to the increasing use of the cut-to-length (CTL) harvesting method in Czechia, connected to harvester technology, from an 11% share on total annual harvests in 2005 to 44% in the year 2019 (Figure 1) [2]. The share of CTL harvesting in 2019 was partially caused by the need to rapidly process timber from the bark beetle calamity. However, forwarders are not used exclusively in tandem with harvesters, they frequently forward timber logged by chain saws, as documented by the fact that there are 453 more forwarders than harvesters in Czechia [2].

Trends similar to those visible in Czechia can be seen in other Central and Eastern European countries, like Estonia (95% share in final cut; 80% in thinning), Latvia (70% share overall) [3]. Besides the economic situation of the country's forestry sector, expansion of the harvester technology depends on conditions as terrain configuration, tree species composition, forest management, etc. Czech conditions enable an increase in usage of

harvester technology. In particular regions, up to 79% of forest area are favorable for harvester deployment [4]. Overall, Dvořák and Natov [5] state that forwarders can be used on approximately 72% (1.88 million ha; 530 million m^3 of timber stocks) of all Czech forests. These forests are located on sites with high load bearing capacities, low-enough slopes, and suitable tree species compositions [1]. Conversely, forestry sectors in countries like Bulgaria or Ukraine, where forests are located on steep slopes, deciduous trees are abundant, and where the forestry sector is undercapitalized are yet to extensively adopt harvester technology [3].
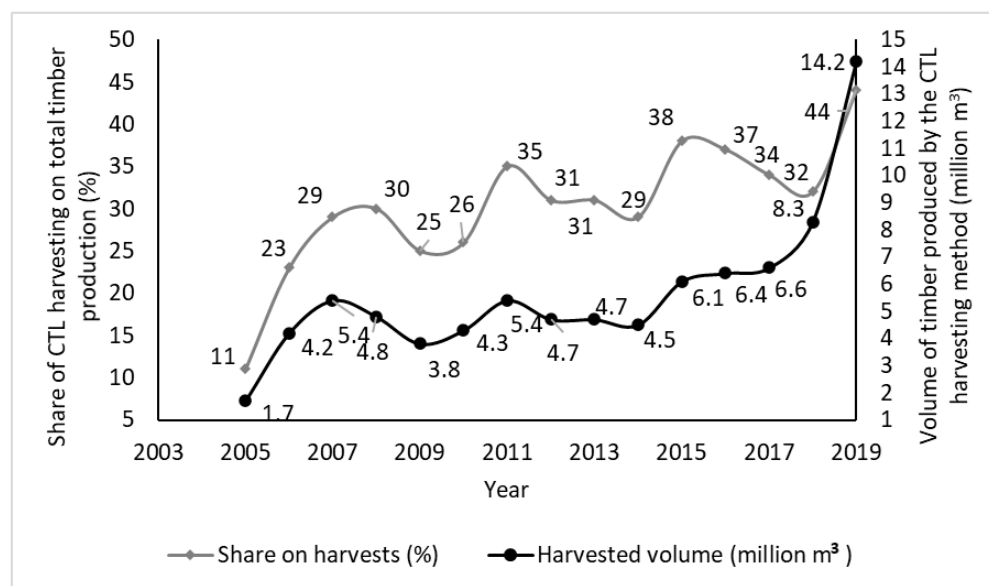

Figure 1. Share and volume of timber produced by the cut-to-length (CTL) harvesting method in Czechia during the years 2005–2019 [2].

Bio-based products and services are likely to become increasingly important and demanded, as they mature in their lifecycles, caused by the role of bioeconomy in climate change mitigation and adaptation. Therefore, any forest value chain needs to maximize the efficiency of all its lings, including timber forwarding as an essential technological operation of extracting timber from the forest floor to the roadside. Any forest harvesting technology must be deployed so that it is productive and profitable. Therefore, prior to any economic analysis, analyzing the operation of a machine is suggested, from which, economic costs are inferred. Many authors focused on predicting or explaining the productivity of forest machinery [5–19]. The accuracy of the analyses is increasing, as they no longer rely on manual measurements and limited data, but rather on the abundant data from the on-board forest machine systems [15,20].

Productivity of forwarders depends on factors such as mean volume of forwarded stem (mean stem volume; MSV), forwarding distance, terrain conditions, harvesting intensity and type, machine performance class, its bunk capacity, and others [1,5,7–11,17,19,21–23]. Forwarders with a bunk capacity up to 3 m^3 are able to forward from 2 to 4.1 m^3/MH, whereas those with approximately 12 m^3 bunks typically forward between 7.1 and 20 m^3/MH [1]. Regarding the MSV, authors report forwarder productivity at 18 to 27 m^3/Productive machine hour with 15 min delays (PMH$_{15}$) in final cuts (high MSV) [14,24], whereas studies [24,25] report a range between 13 and 28 m^3/PMH$_{15}$ in thinning (low MSV). In all of these studies, increasing forwarding distance translates to decreasing productivity. Furthermore, producing shorter logs is more time consuming, i.e., costlier per m^3 than producing longer logs [14,18,26]. Personnel, too, is an important factor in forwarder performance, affecting up to 40% of their productivity [15,27]. In short, there are numerous factors that affect machine productivity. Therefore, to simplify predictions, productivity is often

predicted based on the MSV, and forwarding distance, structured according to machine performance class [28,29].

Increasing productivity typically causes a decrease in operational costs per cubic meter of timber [30]. On the other hand, lower performance machines need smaller investments and can be a good solution for thinning [8,9,31,32]. Nevertheless, forwarders must be utilized properly to ensure the return of invested capital. Their mean utilization is 1581 MH/year [33], thus reaching a utilization rate up to 84% [24].

The aim of this study was to analyze the operational costs of forwarders operated by companies that deployed the machines they owned in forests they managed. Including both smaller and larger machines of the mid-performance class, that were either completely amortized or still undergoing the process enabled to compare the differences between the machines and the effects of this cost group on machine operation.

2. Material and Methods

2.1. Machines Analysed

This study focused on forwarders owned by Vojenské lesy a statky ČR, s.p., Hořovice division (Military Forests and Estates of the Czech Republic; "VLS"; GPS coordinates of the headquarters: 49.78186732228961, 13.988176060239534) and Lesy České republiky, s.p., Forest district Kladská (Forests of the Czech Republic; "LCR"; GPS coordinates of the headquarters: 50.00708154027139, 12.631463299354868), both state owned enterprises. Both the headquarters of VLS and LCR were located roughly at the centre of the respective forest areas the companies managed. The forwarders were used exclusively in forests managed by each company. Forests managed by VLS spanned on 28,000 ha, LCR managed 15,000 ha of forests where their machine operated. Tree species composition was favorable for using the harvester technology in both Hořovice division (83% coniferous species) and Forest district Kladská (90.5% coniferous species). The machines worked on sites suitable for forwarders according to [6], their transfers were minimized, and were rarely deployed to work in other divisions or districts, only to help processing incidental fellings. Forwarders were used primarily in stands up to 80 year of the forest stand age [34].

All forwarders were purchased as new. John Deere 1010 (JDA) was operated between the years 2004 and 2015, Novotny LVS (LVS), was operated between 2008 and 2016, and John Deere 1110E (JDB) was purchased in 2017 and is still in operation (Table 1). Technical parameters of the machines can be seen in Table 2.

Table 1. Operational and investment data of the particular forwarders.

Brand	Date of Purchase (Month/Year)	Purchase Price (EUR)	Date of Sale (Month/Year)	Sale Price (EUR)
John Deere 1010	4/04	177,185	3/15	0
Novotny LVS 5	4/08	84,122	4/16	14,828
John Deere 1110E	2/17	331,481		

Table 2. Forwarder technical information.

Parameter		John Deere 1010	Novotný LVS 5	John Deere 1110E
Base machine	Weight (kg)	11.4	5.5	14.7
	Width (m)	2.68	2.10	2.72
Engine	Type	Perkins 1004-4T	FPT-F34	John Deere 4045
	Power (kw)	82	55	115.5
Bunk	Length (m)	4.63	3.7	4.5
	Width (m)	2.48	2.4	2.7
	Capacity (t)	11	5	11
Boom	Reach (m)	7.2	5.7	10

2.2. Cost Structure

Since 2006, unified cost records were kept for individual machines in the company bookkeeping. No major methodical changes of accounting were introduced since. Comprehensive accounting data on costs were aggregated into four cost groups [35]: (i) amortization; (ii) services; (iii) material; and (iv) personnel costs. Costs such as taxes, financial costs, transfer costs, etc. either did not apply or were not directly connected with the operation of individual machines and were therefore not considered. Records were converted from Czech Crowns into EURO by the mean annual EUR/CZK exchange rate.

2.3. Machine Utilization

Besides the costs, temporal (operational time, delays) and production (forwarded timber volume) parameters of the machines were observed. Temporal utilization of the machines was calculated as the share of operational hours on the scheduled annual working time. The formula was as follows (1):

$$TU = \frac{OT}{OT + DT} \times 100 \tag{1}$$

where:

TU—temporal utilization (machine hours; MH)

OT—operational time of the machines (MH).

DT—delays, i.e., time, when the machines were not operational during working time due to repairs, maintenance or other reasons (scheduled machine hour; SMH).

Productivity of the machines was calculated as the number of produced m^3 u.b. per MH (cubic meters of timber under bark per machine hours.

2.4. Statistical Analyses

Kolmogorov–Smirnov test was used to analyze the normality of distribution of the direct operational costs reached by the machines. Based on the outcomes of this analysis, a non-parametric Kruskal–Wallis test, was used to test the significance of differences between the total operational costs of timber forwarding per production unit (Euros per cubic meter of timber under bark; EUR/m^3 u.b.) reached by particular machines in individual years of their operation.

To enable a visual interpretation of the trends of the cost types of service costs, material costs, and personnel costs, their varying annual values were supplemented by linear trend estimates. The linear trends of particular cost types were constructed by fitting a line that resulted from using a least squares method on the data on the annual costs of a particular type per machine hour reached by the forwarders (i.e., EUR/MH).

3. Results

The gathered data were aggregated and processed into overview tables (Tables S1–S3). Overall, the mean annual utilization of the machines observed in this study ranged from 2080 to 2663 MH, based on the number of shifts and their duration (excluding delays). Utilization rates in particular years ranged between 63.8% and 89.3% for LVS (Table S1), 63.3% and 83.9% for JDA (Table S2), and between 64.4% and 74.3% for JDB (Table S3). Similar to the findings of other authors, operational costs decreased as the effective operational time increased.

The smallest LVS forwarder was deployed in stands with an MSV of 0.11 m^3, forwarding timber over a mean distance of 389 m. Mean annual volume of timber forwarded by the LVS was 14,059 m^3 and the mean annual operational time was 2863 MH. Therefore, the machine achieved a mean productivity between 3.5 and 5.8 m^3/MH. Forwarder JDA was deployed in stands with a MSV of 0.29 m^3. Mean forwarding distance was 321 m and mean annual productivity reached 24,725 m^3, at a mean operational time of 2060 MH. Mean hourly productivity of this machine ranged from 7.4 to 10.3 m^3/MH. Forwarder JDB was deployed in stands with a MSV of 0.71 m^3, forwarding timber over an average

distance of 526 m. Mean annual productivity was 24,321 m^3 with the operational time of 2203 MH on average. The hourly productivity of the JDB ranged from 10.3 to 12.3 m^3/MH. Cost analysis of the three forwarders proved that personnel costs were the most substantial direct operational costs of amortized forestry machinery (Table 3).

Table 3. Direct operational costs per machine hour (MH) of the forwarders.

| Item | Forwarder Brand and Type | | | | | |
| | Novotný LVS 5 | | John Deere 1010 | | John Deere 1110E | |
	(EUR/MH)	(%)	(EUR/MH)	(%)	(EUR/MH)	(%)
Amortization	3.0	11	6.4	16	31.5	42
Services	1.9	7	9.0	22	2.5	3
Materials	4.3	15	11.0	27	14.6	20
Personnel	19.2	67	14.2	35	26.1	35
Total	28.4	100.0	40.6	100.0	74.7	100.0

Amortization expenses were calculated based on data available in Table 1 and Tables S1–S3. The purchase price, ranging from 84 to 331 thousand EUR. The share of amortization on the total direct operational costs over the life span of the forwarders ranged between 12.5% and 15.7%. In those years, when the machines were not fully written-off, they amounted for approximately 42% of the annual direct operational costs of the machines. Due to the changes in the legal framework in Czechia, the amortization period differed for individual machines. John Deere 1010 was amortized over the course of eight years, until the year 2012, whereas LVS was amortized over the course of six years (until the year 2013), and was then sold for 14,800 EUR. The newest forwarder, JDB, is being amortized since February 2017. After amortizing the whole purchase price of the machine and related materials, no costs related to this group were recorded. Amortization amounted for 3.00 EUR/MH for LVS, 6.37 EUR/MH for JDA, and 31.54 EUR/MH for JDB. The effects of this cost group on the direct operational costs of a machine were apparent, as was the increasing trend of this cost group over time (mean annual increase was 1.18 EUR/MH), caused by the increasing purchase prices (Figure 2).

The share of service costs on direct operational costs ranged between 3.3% to 22.1%, i.e., 1.87 to 8.98 EUR/MH (Figure 3). For LVS, service costs reached 7% of direct operational costs (1.87 EUR/MH), for JDA they reached 22.1% (8.98 EUR/MH), and for JDB, they reached 3.3% (2.45 EUR/MH).
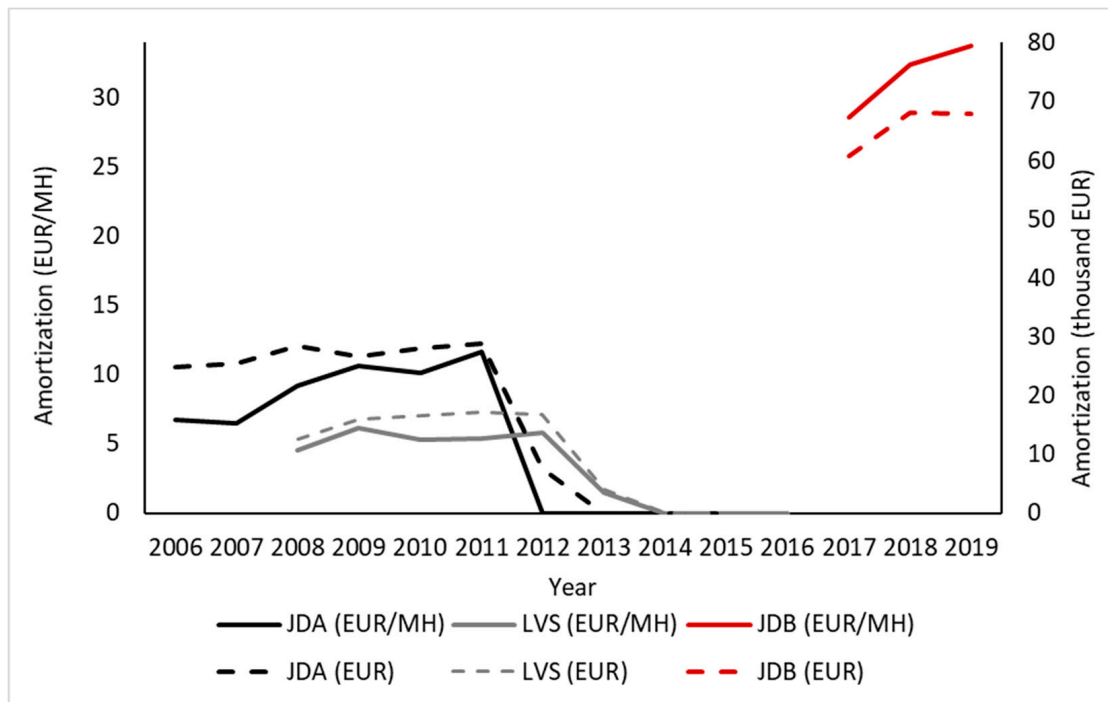
Figure 2. Amortization of the forwarders in the observed period. MH—machine hour; JDA—John Deere 1010; LVS—Novotný LVS5; JDB—John Deere 1110E.
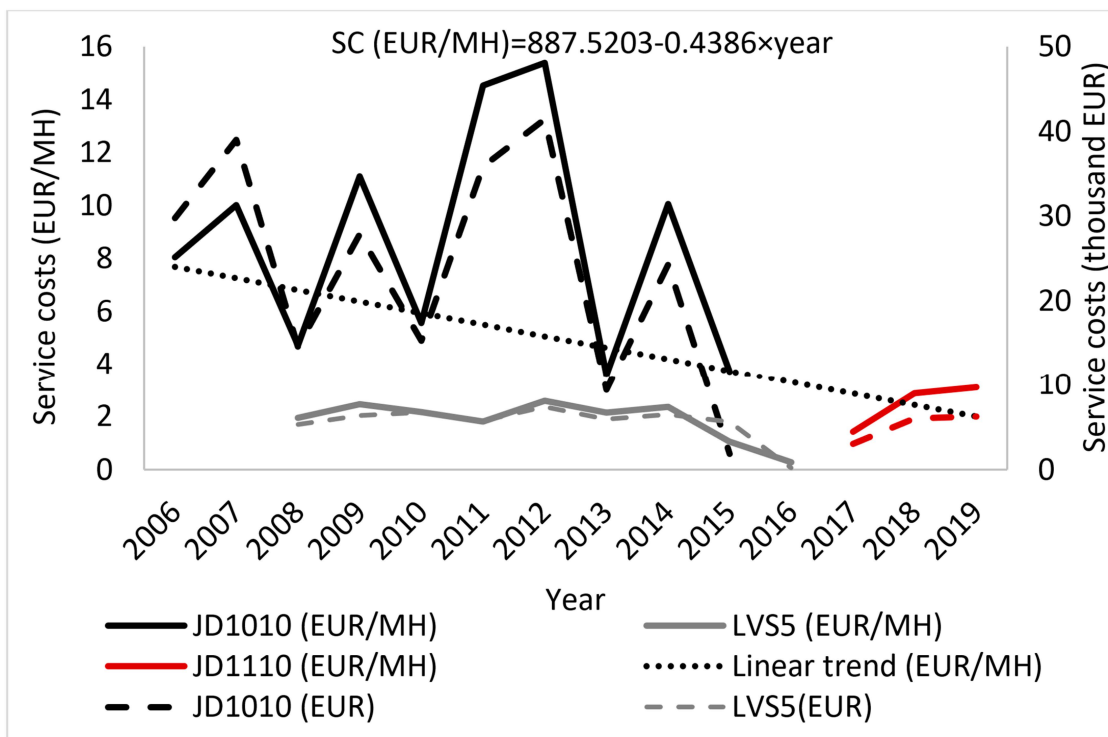

Figure 3. Service costs (repairs and maintenance) of the forwarders in the observed period. MH—machine hour JDA—John Deere 1010; LVS—Novotný LVS5; JDB—John Deere 1110E; SC—service costs.

The share of material costs on the direct operational costs was, on average, 14.9% (4.27 EUR/MH) for the LVS forwarder; 27.1% (11.02 EUR/MH) for JDA, and 19.5% (14.59 EUR/MH) for the JDB forwarder (Figure 4). The higher consumption of mate-

rials by the John Deere machines was caused by their greater engine performance rating (Table 2), which translated into their higher productivity figures (Tables S2 and S3).
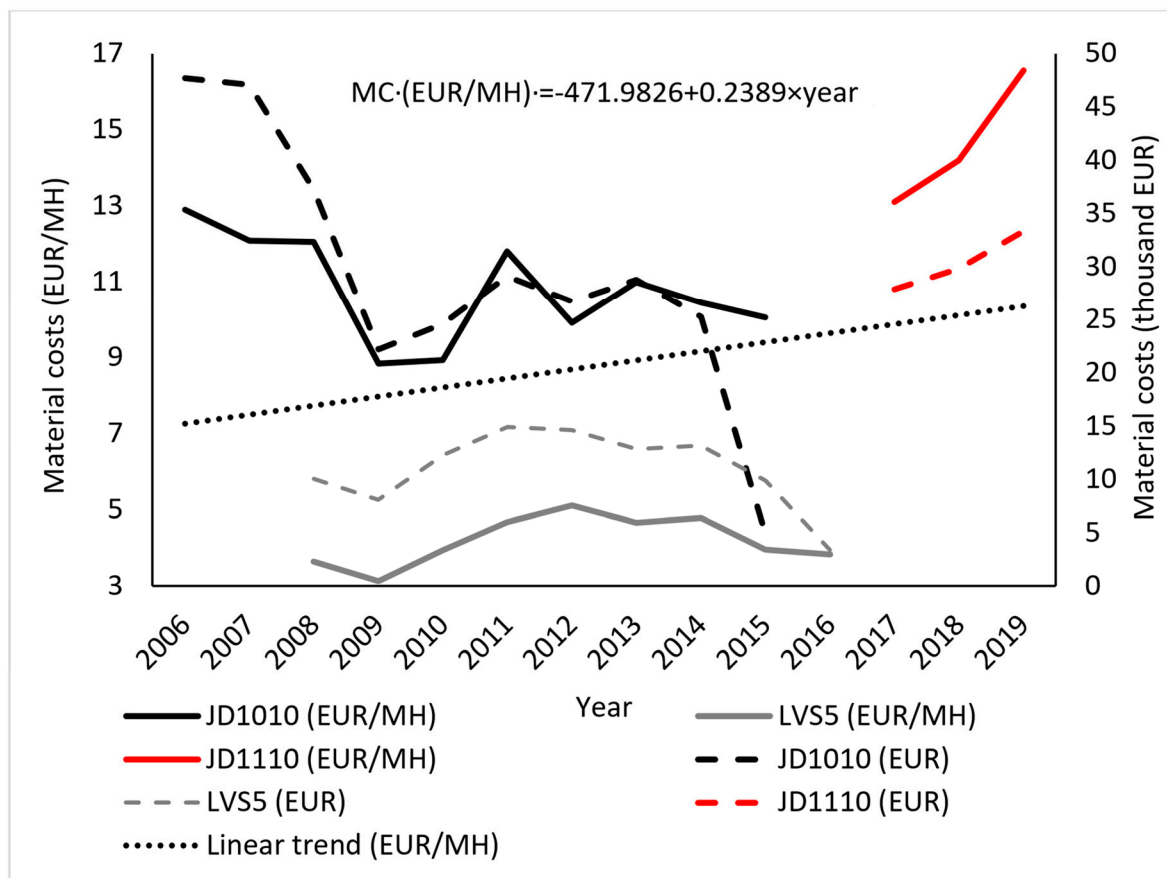

Figure 4. Costs of material (fuel, tires, spare parts) of the forwarders in the observed period. MH—machine hour JDA—John Deere 1010; LVS—Novotný LVS5; JDB—John Deere 1110E; MC—material costs.

The share of personnel costs on the direct operational costs of LVS was 65.6% (19.22 EUR/MH) on average, for JDA it was 35.1% (14.26 EUR/MH), and for JDB, it was 35.0% (26.14 EUR/MH) (Figure 5).
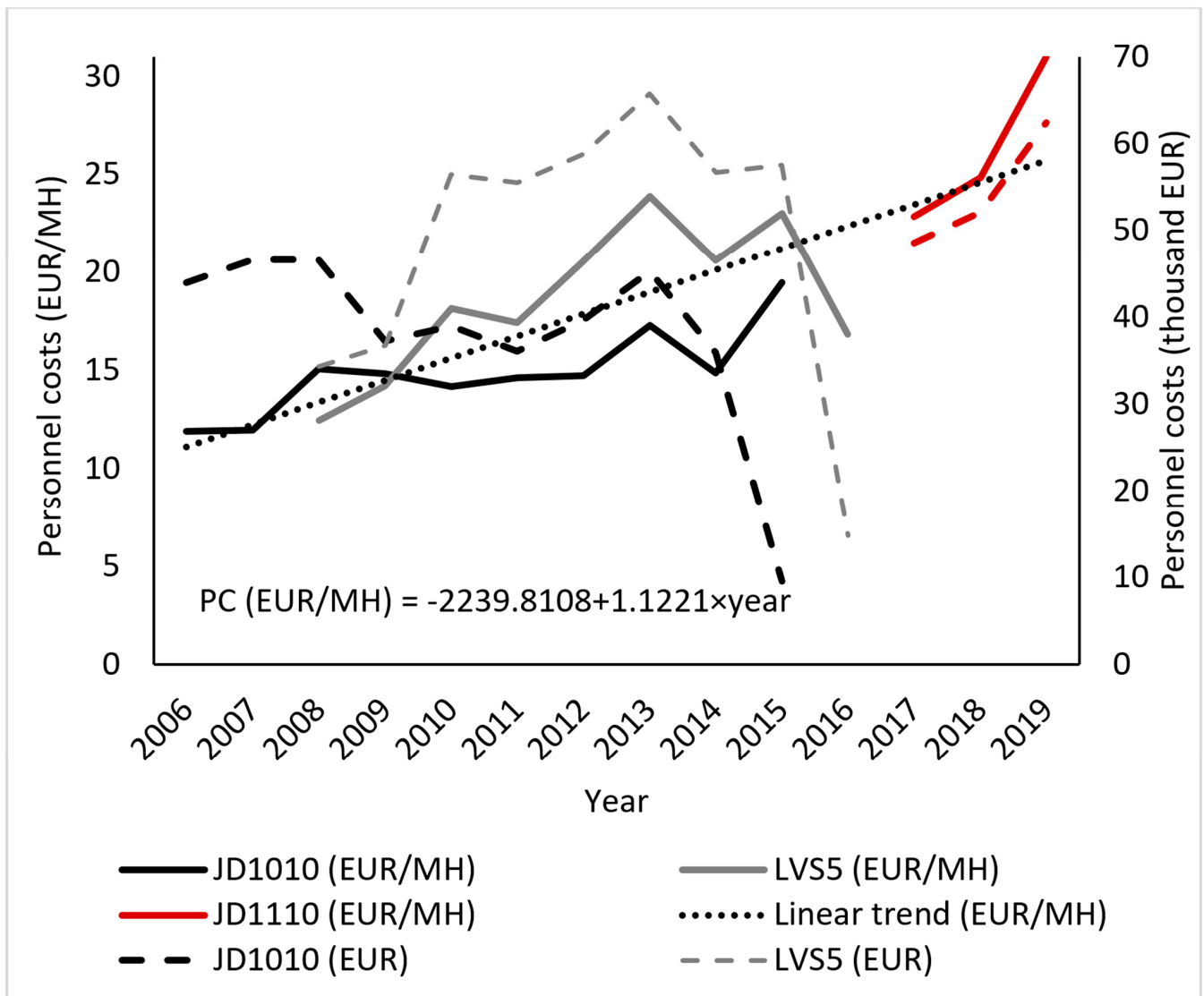
Figure 5. Personnel costs of the forwarders in the observed period. MH—machine hour JDA—John Deere 1010; LVS—Novotný LVS5; JDB—John Deere 1110E; PC—personnel costs.

The LVS forwarder, forwarded timber mostly from stands up to 40 years of age. The direct operational costs per cubic meter of forwarded timber ranged from 3.60 to 7.93 EUR/m^3. John Deere 1010 reached costs ranging from 3.55 to 6.10 EUR/m^3, whereas JDB reached costs from 6.22 to 7.22 EUR/m^3.

The Kruskal–Wallis test, showed there were no significant differences between the three forwarders of two ends of the performance class ($p > 0.05$) (Figure 6).
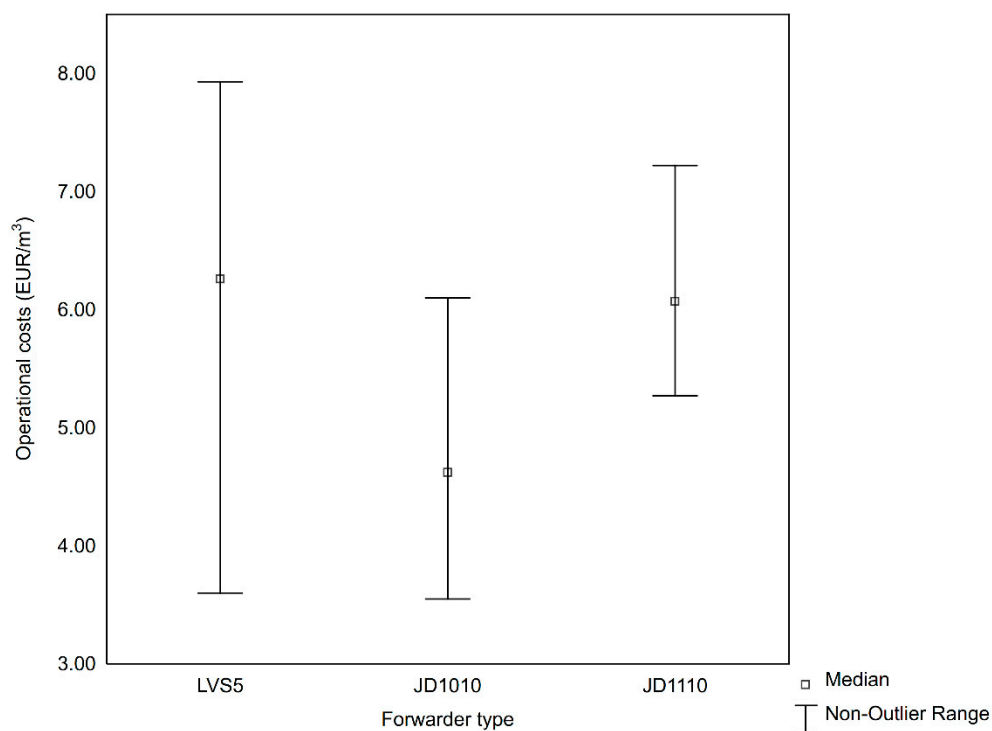
Figure 6. Results of the analysis of variance showing no statistically significant differences between the observed forwarder direct operational costs.

Besides the MSV, forwarding distance affects forwarding productivity per production unit (cubic meter) the most (Figure 7). Depending on the forwarding distance and MSV, direct operational costs per machine hour range from 4.34 to 6.29 EUR/m^3.
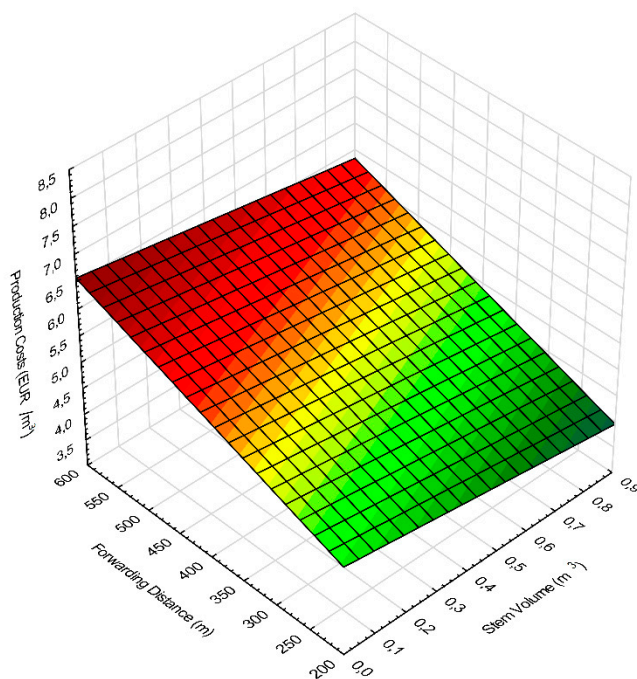

Figure 7. Relationship between direct operational costs of timber forwarding, mean volume of forwarded logs, and forwarding distance.

Direct operational costs of timber forwarding ranged from 3.55 EUR/m^3 to 12.03 EUR/m^3 based on the machine observed and the MSV.

Vojenské lesy a statky operated their forwarders in tandem with a John Deere 770D (years 2008–2016) and a John Deere 1070 (years 2006–2014) harvester [36]. Based on the overlapping data from the harvesters and forwarders, we found that annual direct operational costs of the John Deere 770D and LVS tandem ranged from 150,000 to 278,000 EUR throughout the years 2008–2016, whereas the John Deere 1070D and JDA tandem reached annual direct operational costs in the range of 216,000 to 372,000 EUR throughout the years 2006–2014 (Figure 8).
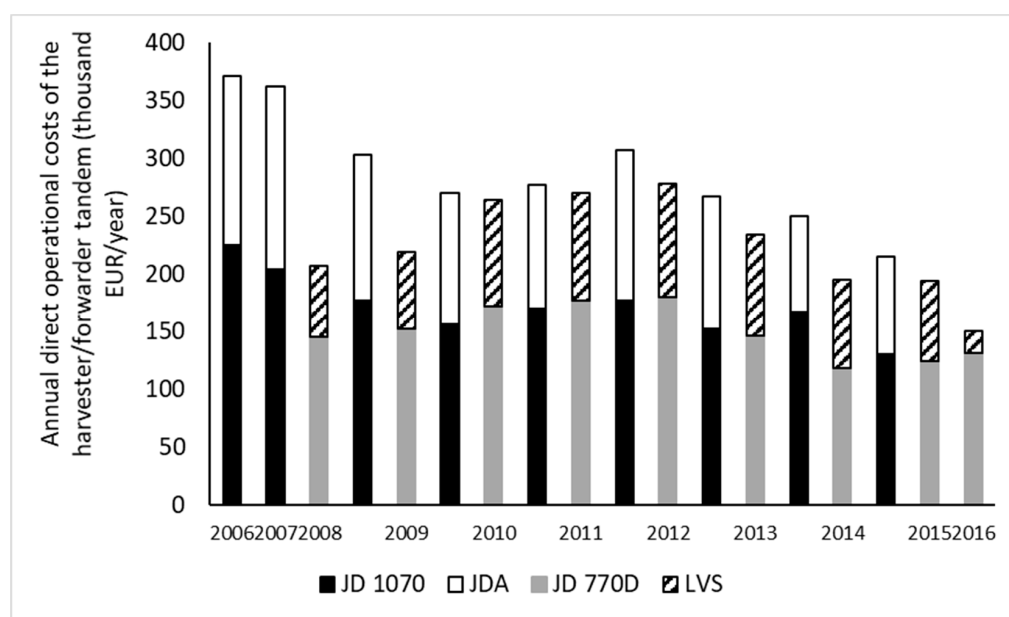

Figure 8. Annual direct operational costs of the harvester/forwarder tandems (supplemented from [37]). of the forwarders in the observed period. JD 1070—John Deere 1070 harvester; JDA—John Deere 1010 forwarder; JD 770D—John Deere 770D harvester; LVS—Novotný LVS5 forwarder.

4. Discussion

Confronting the results of this study with those from other authors was challenging. The costs were presented for particular countries, with all the differences in the underlying legal and economic frameworks, differing cost structures, reporting systems, production inputs, etc. The studies frequently observe technologies over a limited time, as opposed to observations throughout the whole amortization period. Most of them are case studies performed in a narrow interval of production conditions (e.g., single forest stand or a few), which make the results difficult to generalize. Several studies analyze the operational costs of harvesters or the whole harvester/forwarder tandem, but few separate the operational costs of timber forwarding [37,38]. However, analyzing the direct operational costs of timber forwarding separately is important, as forwarders do not have to work in tandem with harvesters [2].

The operational costs of timber forwarding ranged from 28.4 to 74.7 EUR/MH in the presented study. The forwarders were used in favorable settings, with suitable tree species compositions, sufficiently bearing soils, and mild slopes. These conditions play a substantial role in machine productivity, and subsequently in their operational costs, as the base over which the costs incurred are spread either scales up or down. Therefore, conditions that are connected to decreasing productivity, such as steep uphill slope, smaller MSV, salvage or incidental logging type, forwarding distance, limited operator experience, etc. cause an increase in forwarding costs [7,10,15,19]. Another factor were the differences in the structure of assortments produced. Transporting pulpwood can result in 43% higher costs compared to transporting sawlogs [26]. Unfortunately, we could not analyze this, as timber production varies greatly in short periods of time and records on the structure of assortments produced were impossible to link to cost data ex post. On the other hand,

downhill slope, optimized use of machine payload, limiting the number of assortment types, introducing a midfield to the operations, and using experienced operators can increase forwarder productivity, thus improving their operational costs [7,9,15,18].

Other than that, the aforementioned factors affect forwarding costs also in a more direct manner. With increasing uphill slope, forwarding distance, delays caused by operators or longer periods of time spent loading or unloading, the amount of consumed materials, such as fuel or tires, also increase. In the presented study, their share ranged between 4.3 and 14.6 EUR/MH, though in certain years, they increased by purchase of new tires (Figure 4). Besides fuel and tires, material costs included spare parts fitted or exchanged by the machine operators (such as chains, bars, and other parts of the power saw mechanism, etc.), replacement of more substantial machine parts were contracted to dedicated repair shops and were recorded as services. To compare, Austrian researchers reported that between the years 2004 and 2008, 18 forwarders with engine performance between 82 and 150 kw reached mean material costs of 13 EUR/PMH_{15} [38].

Longer operational times also lead to excessive wear and tear or machine parts, which translate to increased service costs. However, perhaps the most important factors are the operators and their handling of the machine and work at hand [18,39]. If the machinery is well cared for and operated thoughtfully, service costs should theoretically increase only by the rate of inflation. This can be seen on Figure 3, when observing JDA. The high costs during the first two observed years can be attributed to the continuous operation in three shifts. The reckless approach of the operators in the first years caused several severe accidents (e.g., tearing a power line on the machine, which caused electrical damage to the machine and a need for a general repair of the engine). Figure 5 shows that using the three-shift operation with multiple operators, i.e., maximizing the utilization of the JDA forwarder, contributed to increased personnel costs during the first years of its operation. For these reasons, the company reduced the machine operation to a single 10 to 11 h-long shift per day, with a maximum of two operators in the rotation. Overall, personnel costs observed in this study were higher than, e.g., the 12 EUR/MH reported by Jiroušek et al. [28].

On the other hand, typical fixed costs, such as amortization, do not depend on machine utilization rates. In Czechia, a company is allowed to claim only a fixed amount of money per year as amortization. The amount depends on the amortization group (based on the typical lifespan of the machine that is being amortized) and the purchase price of the machine and its auxiliary systems. The purchase price of forest machines depends on the brand, capacity, boom type, and other equipment installed [28,40,41]. Therefore, maximizing utilization of forest machines will decrease their amortization costs per temporal or production unit, creating a possible competitive advantage for companies that can achieve the high utilization rates of their machines.

The machines observed were utilized to a standard degree, exceeding the 2000 h per year threshold of standard eight-hour shifts. To compare, other authors report mean annual temporal utilization of forwarders between 212 and 4,418 MH [34,40,42]. Rather than absolute utilization in MH, utilization rates enable an easier comparison between several cases. In this study, machine utilization rates ranged between 63.3% and 89.3% of the scheduled time. Though these figures are lower than those of the machines observed by Proto et al. [10], forwarders typically reach about 75% to 80% rates [24,43]. Sufficient utilization of the machines plays a substantial role in their operational economy. Any company that operates forest machines therefore needs to optimize the size of their machines, so that the machines are able to work in suitable conditions. It is therefore vital to prepare forest stands for deployment of such machines in advance through proper planning of forwarding trail network and roadside landing location optimization, to minimize travel of the machines. Aside from planning the logging operations, a positive outcome of this study was the finding that there is no significant increase in operational costs when comparing machines from the opposite sides of their performance class. Thus, buying machines on the higher end of the performance class can be beneficial for companies that operate as

contractors of logging operations, as will be able to deploy them in more diverse conditions. On the other hand, companies that own sufficient forest area have an even greater advantage, as they can scale the machine size to the operations they expect to be carrying out in the forests they own, thus achieving their high utilization rates.

5. Conclusions

Total operational costs increased annually for the LVS and JDB forwarders, a trend caused by the increase of personnel costs in case of the LVS and personnel and amortization for the JDB. Other costs types stagnated (materials consumption or services) for these machines. The JDA exhibited a decreasing trend, caused by the decreasing overall utilization of the machine and restriction of its operation from three shifts at the beginning of the observed period to one at its end. The differing trend of each machine pointed to the importance of optimizing the operational mode of forest machines to maximizing the efficiency of their use rather than maximizing their overall utilization. This conclusion was supported by the fact that the larger and more expensive machines did not significantly differ from the rather small LVS in terms of costs per production unit. We would like to point out that companies that operate their machines in forests they own have an advantage over machine operators who rely on being contractors of harvesting operations. The latter must consider the wider set of conditions, for which their machines are to be used, whereas the former can scale the machines they intend to purchase and the parameters of those machines exactly to the conditions found in their forests, thus decreasing the potential for inefficiencies or underutilization of their machines.

In terms of costs types, the companies that operate forwarders should pay attention to their personnel, as this was the only cost type that exhibited a steady increase for all observed machines. The trend was likely driven by the developments on the labor market, increasing share of CTL operations on total harvested volume in Czechia and the subsequent increasing competition for skilled operators by companies operating CTL machines. The second largest cost group was amortization, in the years when the machines were amortized. This points to the high capital intensity of fully mechanized logging, which should be compensated by high productivity and lower sum of operational costs per production unit over the lifespan of the machinery purchased, to make the purchase a sound business decision.

The costs of forest operations will trickle down to the price of bio-based products, affecting their ability to compete with their traditional, fossil-based counterparts. Therefore, increasing the efficiency of forest operations and all other parts of forest value chains is a key element of increasing the scale and scope of the global bioeconomy, an economic concept expected to play a substantial role in mitigating the effects of climate change. If we want to simultaneously keep or improve the ergonomics and quality of work environment, for which there is a considerable social demand, we need to achieve minimal costs of production per production unit through sophisticated machines, such as forwarders and gradually decrease the direct exposure of workers to the forest exterior.

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