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PRODUCTIVITY MODELS AND COSTS OF COMBINED SKIDDER – HARVESTER IN CONIFEROUS FORESTS

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Abstract

In addition to natural pine forests in Bulgaria, there are also large artificial plantations (over 1.5 million ha), created in the period of 1950–1990. Large areas with non-thinned coniferous plantations located at low altitudes are associated with a high probability of reduced growth and significant health problems. Traditionally, adapted agricultural tractors are the most widely used equipment for timber extraction in Bulgaria. The shortage of work force due to labor-intensive and unattractive logging work is one of the reasons for making efforts to introduce more advanced, multipurpose equipment. However, in Bulgaria the use of harvesters is limited by the predominance of deciduous forests, steep terrains and by the maximum allowed harvesting intensity of 30 %. The latter requirement often makes modern logging equipment unprofitable. In an attempt to overcome some of these limitations, the use of a combined wheeled skidder-harvester (SH) has been introduced in the eastern Rhodopes Mountains in the last few years. The SH works as a harvester and fells the accessible trees located on the skid roads and on the corridors. The remaining marked trees are felled manually by chainsaw. The felled trees are dragged to the machine by a two-drum winch equipped with a remote control, skidded to the landing where they are delimbed, bucked and piled by the SH. The mean productivity of the SH which stands for a mean skidding distance of 69 m, a mean bunching distance of 14 m, a mean load volume of 4.06 m^3, was estimated at 9.38 $m^3 \cdot PMH^{-1}$ (8.27 $m^3 \cdot SMH^{-1}$) timber piled at landing, which is comparable to two typical logging teams with adapted tractors and 4–5 workers in each team. The gross costs per unit done by the SH (14.24 €$\cdot m^{-3}$) are within the regional level for coniferous stands.

Key words: cycle time, economic evaluation, shelterwood system, work elements.

Introduction

The area of forests in Bulgaria is over 4.23 million ha (including 3.858 million ha of woodlands). The total stock is 681 million cubic meters (over bark). The share of deciduous and coniferous tree species by area is 71 % and 29 %, respectively, while the share in the total stock is 55.5 % and 44.5 %, respectively (EFA 2020). Bulgaria annually produces on average about 8.0–8.3 million cubic meters (over bark) of the stock or about 6.6–7.0 million cubic meters (under bark) timber (EFA 2019).

In addition to natural pine forests, there are also large artificial plantations (over 1.5 million hectares), created in the period of 1950–1990. They consist mainly of Scots pine (*Pinus sylvestris* L.) (48 %) and Austrian pine (*Pinus nigra* Arn.) (41 %) (EFA 2019). Most of the forest plantations were created to ensure anti-erosion functions and to improve degraded forests; accordingly, due to their scale, they have a significant environmental function (Milev et al. 2017). Large areas with artificially created non-thinned coniferous plantations located at low altitudes are associated with a high probability of reduced growth and significant health problems, which present a serious challenge for the Bulgarian foresters. About 30 % of the Scots pine plantations are located at lower altitudes compared to their natural distribution in Bulgaria. 35 % of them are located between 700 and 1000 m a.s.l., where only 8 % of the natural forests of these tree species are found. The distribution of Austrian pine plantations is similar in terms of altitude, with 76 % of them being distributed below 700 m a.s.l., where only 5 % of natural forests of these species are found. These two species provide valuable wood with a wide application in the wood processing and construction industries. In the recent decades, there has been an increased drought stress due to higher recorded temperatures and long rainless periods during summer and autumn, which contributed to reducing the growth and deteriorating the health of many artificial plantations, especially those of Scots pine, located at low altitudes (MOEW 2019).

The selection of the most suitable machines is crucial for the assessment of technical, economic and environmental indicators during the harvesting operations in artificial coniferous plantations.

Traditionally, adapted agricultural tractors are the most widely used equipment for timber extraction in Bulgaria, as well as in the Balkans, the Carpathians, Italy, etc. (Borz et al. 2013a, 2013b, 2015; Spinelli et al. 2013; Moskalik et al. 2017; Bodaghi et al. 2018; Proto et al. 2018; Cataldo et al. 2020).

Wheel cable skidders are used in many harvesting systems due to their long winch cable (60–100 m) giving a better opportunity to reach otherwise inaccessible trees. Worldwide the wheel skidder is one of the most used machines in mountain logging for slopes under 10–20° (Georgiev and Stoilov 2007).

Skidding distance had been found to be one of the most relevant independent variables for modeling the work time consumption (Sabo and Poršinsky 2005; Özturk 2010a, 2010b; Gallis and Spyroglou 2012; Borz et al. 2013; Ghaffariyan et al. 2013; Vusić et al. 2013). The greatest amount of studies have been conducted for skidding distances up to 400 m (Sabo and Poršinsky 2005; Gallis and Spyroglou 2012). Borz et al. (2014) adds to the most significant independent variables for the time consumption estimation in a group shelterwood system also winching distance and number of logs forming a load.

Skidders may successfully replace modified farm tractors without requiring any substantial changes in the conventional harvesting methods, thus making innovation less traumatic for the logger's mind and wallet (Spinelli et al. 2021).

While the total productivity of the wood harvesting methods is comparable across EU countries, unit cost, particularly with the less mechanized technologies, differs greatly between countries due to the different cost of labor cost. The lowest level of mechanization for logging processes is observed in Bulgaria, Romania, Slovakia and Ukraine. This is mainly due to the availability of relatively cheap labor (Moskalik et al. 2017).

The productivity of a harvester depends on the harvested tree volume. As soon as the trees volume increases, the productivity of the harvester increases as well. Closer to the technological corridors, stands are thinned more intensively than in more distant areas; the most common reason for such difference is the insufficient accessibility of trees located far from the strip roads (Pētersons 2010). The time consumption per cubic meter is also higher in sparse shelterwoods than in dense shelterwoods. Most of this increase is due to a longer driving time because fewer trees are harvested (Hånell et al. 2000).

The productivity of a John Deere 1270 D harvester operated in southeastern Bulgaria during clearcutting after forest fires and calamities in Scots pine and Austrian pine plantations was 51 m^3 per day. The distribution of the harvester work cycle by elements was: 50 % – time for trees processing, 13 % for trees felling, 13 % for moving in the stand, and 24 % for the remaining time, while the distribution of the forwarder work cycle is: 33 % of the time for loading, 12 % for unloading, 28 % for traveling, 13 % for moving in the cutting area and 14 % for the remaining time (Dinev and Vardunski 2014).

The longer time and higher logging cost in the shelterwood system (compared with the clearcutting system) were mostly related to the establishment of the shelterwood (Hånell et al. 2000).

The economic challenges faced by the Bulgarian forester are very severe. The shortage of work force due to labor-intensive and unattractive logging work justifies an effort to introduce more multipurpose equipment. In Bulgaria, the introduction of harvester technology is limited by the predominance of deciduous forests, steep terrains and by the maximum allowed harvesting intensity of 30 % (in poplar plantations – up to 50 %). The latter requirement often makes modern logging technologies with harvesters unprofitable.

In an attempt to overcome some of these limitations, the use of a combined skidder-harvester (SH) has been introduced in Bulgaria for the last few years. The combined machine works as a harvester and fells the accessible trees located by the skid road and the corridor. The remaining marked trees in the midst of the stand are felled manually by chainsaw. The felled trees are pulled to the skid road by a two-drum winch with remote control and then skidded to the landing where they are delimbed, bucked and piled by the combined machine.

Currently, there are no studies on the time consumption, productivity and cost of the combined skidder – harvester used in different sylvicultural systems and under different terrain conditions; therefore, one cannot assess the influence of different operational and technical parameters on its productivity and costs. Such studies are needed to evaluate the application of this type of combined machinery in logging from a sylvicultural, technical and economic point of view.

The aims of the present study were: (i) to determine productivity rates and costs using combined wheel cable skidder – harvester, (ii) to develop cycle time and productivity prediction models, and (iii) to estimate the application in logging operation for such type of combined machine in Bulgaria and the eastern Rhodopes in particular, as well as in many European countries' coniferous plantations.

Material and Methods

Study site and work organization

The study was carried out in the Krumovgrad State Forest Range (subsidiary of South Central State Enterprise, Smolyan), located in the eastern Rhodopes, Kardzhali Province, Bulgaria. Stand and operation characteristics are shown in Table 1.

Table 1. Characteristics of the test site.

Parameter	Characteristics
Location	Egrek
Elevation	550 m a.s.l.
Species composition	Scots pine – 80 % and Austrian pine – 20 %
Stand age	55 years
Stand type	High forest plantation
Total area	22.2 ha
Stand density	929 trees per ha
Relative stocking	0.8
Harvesting method	Combined regular and shelterwood cutting, intensity 25 %
Average tree height	Scots pine – 17 m, Austrian pine – 16 m
Average DBH of a tree	Scots pine – 24 cm; Austrian pine – 30 cm
Average slope gradient	19° (34 %)
Growing stock	7260 m^3 (336 $m^3 \cdot ha^{-1}$)
Allowable cut	1860 m^3 (84 $m^3 \cdot ha^{-1}$)
Number of trees for cut	5154 (232 $trees \cdot ha^{-1}$)

The Scots pine (*Pinus sylvestris* L.) and Austrian pine (*Pinus nigra* Arn.) trees were transported by a wheel cable skidder – harvester (SH) as semi-suspended full trees (except the stumps). Skidding direction was downhill and trees were felled manually by a chainsaw or by a harvester head.

The combined wheel cable skidder – harvester (SH) operated in sub-compartment 592-v (41°19′54.56" N, 25°36′39.25" E). Field observations were carried out on 31 work cycles (turns) of the SH.

The SH work team consisted of two people, one of which was the skidder and harvester operator, the second one was the chainsaw operator and chokerman. The work team had more than 2 years of experience with studied machine and they were 30–45-years-old.

An articulated four-wheel-drive HSM 805 ZL (HSM Hohenloher Spezial-Maschinenbau GmbH & Co. KG, Neu Kupfer, Germany) double-drum wheeled cable skidder, equipped with a knuckle-boom loader and a Woody 50 harvester head (Konrad Forsttechnik GmbH, Preitenegg, Austria), as shown in Table 2, was used for the tests.

Table 2. Technical data of the studied HSM 805 ZL double-drum cable skidder – harvester.

Parameter	Characteristics
Engine	IVECO NEF, 4 cyl. Common Rail Turbo / TIER 3B
Engine output	125 kW (170 DIN horsepower) at 2200 rpm
Max. torque	700 Nm at 1500 rpm
Engine capacity	4.5 liters
Transmission	HSM High Speed Drive, 2-step NAF transfer gearbox
Axles	Planetary axles, 100% separately selectable differential locks, front and rear
Brake	2-circuit brake, disk brake running in an oil bath, spring-loaded parking brake

Steering	Articulated steering with 2 cylinders, 45° steering angle
Tank capacity	Diesel: 175 l; AdBlue: 25 l; Hydraulic fluid: 90 l
Hydraulics	Load sensing
Pump output	Flow rate: 232 liters/min at 1600 rpm, pressure: up to 350 bar
Hydraulic fluid	Saturated, synthetic ester
Cabin	• HSM Panorama comfort cab; • ROPS, FOPS, OPS tested safety cab; • Swivel seat device, air-suspended comfort seat; • Heating/air-conditioning.
Logging equipment	• Fixed front polder shield, 2000 mm wide; • Lowerable straight shield; • Adler HY 20 (2×100 kN) double-drum winch, max. cable take-up of Ø14 mm, 100 m; • Epsilon crane M80 R59, lifting moment 114 Nm, range 8.0 m.
Harvester head	Woody 50
Chain tensioner system	Hydraulic
Chain speed	40 $m \cdot s^{-1}$
Length of the saw guide bar	750 mm
Max. cutting diameter	550 mm
Delimbing diameter	40–550 mm
Max. grapple opening	1030 mm
Dimensions	
Length	6986 mm
Wheel base	3820 mm
Height	3170 mm
Width	2360 mm
Weight	12,800 kg

Productivity study and costs

A detailed time and motion study was conducted to estimate the duration of work elements and productivity of the SH in the given conditions. A work cycle was assumed to be composed of repetitive elements (Stokes et al. 1989, Olsen et al. 1998).

The work cycle of the SH was composed of the following repetitive components:

- travel unloaded (TU) along the skid road;

- felling (F) – time for cutting standing trees by the harvester head causing them to fall as a result of the cutting;

- bunching – time for winching and gathering the tree load including the time for maneuvers and choice of position. Bunching can be divides into maneuvering (M), outhaul of the main cable and hook (OH), and load inhaul (I) to the skidder;

- travel loaded (TL) along the skid road;

- processing (P) – time for delimbing (removing branches from a tree) and bucking (cutting felled and limbed trees into sections) by the harvesting head;

- sorting and piling (SP) – time for picking up the logs or bolts and depositing in large piles by knuckle-boom so the logs are horizontal and parallel to each other and the ends are approximately in the same vertical planes;

- delays (D) include the rest, personal delays, organizational delays, service, and repair.

The time-motion study was designed to evaluate the duration of work elements and productivity of the SH and to identify those variables that are most likely to affect it. Each work cycle was individually measured by a stopwatch. The productive time was separated from the delay time. Skidding distance, slope gradient of the skidding road, and outhaul distances were measured with a professional laser range-finder with clinometer. Load volume was determined by measuring the length and the mid-length diameter of all logs in each load.

Machine costs were calculated using the COST model (Ackerman et al. 2014). In order to calculate the production cost for 1 m^3 timber, the cost analysis employed the following parameters: the number of operators, the hourly cost for an operator, the hourly cost of the machine, the volume of extracted timber and productive machine hours (excluding all delay times). The machine cost per hour was reported both as productive machine hours excluding delays and scheduled machine hours including delays. The purchase price and operator wages required by the cost calculations were obtained from the accounting records (Proto and Zimbalatti 2016). Labor cost was set at 11.55 €·SMH^{-1} (both for the SH operator and the chainsaw operator) including the indirect salary costs. Diesel fuel consumption was calculated using diesel fuel consumption norms. A salvage value of 10 % of the purchase price was assumed and the Value Added Tax (VAT) was excluded.

Cost calculations were based on the assumption that companies worked for 150 working days in a year and the depreciation period is 10 years. For extraction work, this amounts to 130–150 working days per year (20–21 working days per month) at an average of 6–7 scheduled working hours per day (assuming one to two hours spent on lunch, rest and other breaks). Thus yielded annual working hours are 910–1050 SMHs with a 70 % use coefficient (Spinelli and Magagnotti 2011, Spinelli et al. 2014, Proto et al. 2018).

Data analysis

Regression analysis was performed on the experimental data of the SH in order to develop prediction equations for estimating time consumption and productivity. The variables used in the modeling approach included skidding distance L, bunching distance l, load volume per cycle V, slope gradient of the skidding road s, the number of trees in a load n_{tr}, and the number of processed assortments and logs n_{as}. The statistical analysis consisted of identification and exclusion of outliers, correlation analysis for independent variables with a correlation coefficient set at $R \geq 0.75$ as an acceptable threshold to exclude the independent variables from regression analysis for reasons such as the inflation of determination coefficients. The descriptive statistics of the variables were computed and a stepwise backward regression procedure was used to model the variability of the cycle time and productivity as a function of independent variables.

The confidence level used for regression analysis was 95 % ($\alpha = 0.05$) and the assumed probability $p < 0.05$. Independent variables are significant at $p < 0.05$, i.e. strong presumption against neutral hypothesis. To process the experimental data Statistica 8 (StatSoft Inc., Tulsa, OK, USA) software was used.

Results and Discussion

Work cycle time

Tables 3 and figures 1 and 2 show the main descriptive statistics related to the time consumption and skidding and bunching distances during the field observations carried out on 31 work cycles (turns) of the SH.

Processing, including delimbing and bucking, accounted for the largest share (34 % and 31 %, by excluding and including delays, respectively), followed by the piling (25 % and 22 %, by excluding and including delays, respectively), load inhaul (10 % and 9 %, by excluding and including delays, respectively), outhaul and hook and loaded travel (8 % and 7 %, by excluding and including delays, respectively), felling (7 % and 6 %, by excluding

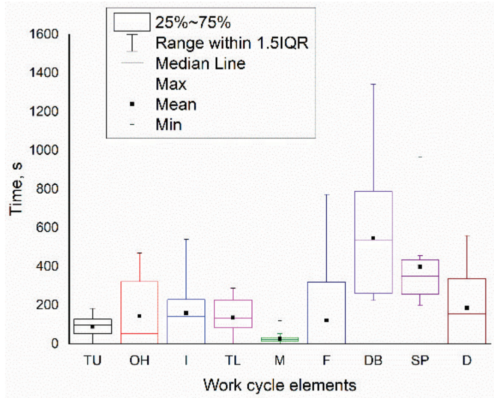


Fig. 1. Elemental time consumption.

Table 3. Descriptive statistics of the time consumption and operational distances.

Variables	Duration, s			Distance, m		
	Mean value ±SD	min	max	Mean value ±SD	min	max
Travel Unloaded (TU)	92 ±38	0	184	69 ±38	0	131
Maneuvering (M)	27 ±21	0	119			
Outhaul and hook (OH)	133 ±149	0	410	14 ±9	0	31
Load inhaul (I)	165 ±155	0	541	14 ±9	0	31
Travel Loaded (TL)	140 ±88	0	288	69 ±38	0	131
Felling (F)	114 ±224	0	773			
Processing (P)	557 ±305	224	1342			
Sorting and Piling (SP)	404 ±198	198	967			
Delays (D)	192 ±184	0	560			
Total cycle time	1824 ±687	680	3572			
Delay-free cycle time	1632 ±701	680	3421			
Number of trees per cycle	4.07 ±1.01	3	6			
Number of assortments per cycle	35.67 ±10.06	24	66			
Cycle load volume, m^3	4.06 ±1.40	2.4	7.04			
Productivity, m^3 per PMH*	9.38 ±1.50	7.37	13.76			
Productivity, m^3 per SMH*	8.27 ±1.62	5.78	13.76			
Number of cycles per SMH*	2.29 ±0.95	1.05	5.29			
Mean speed, $km{\cdot}h^{-1}$	1.88 ±0.96	0	3.21			
Speed loaded, $km{\cdot}h^{-1}$	1.59 ±0.88	0	2.98			
Speed unloaded, $km{\cdot}h^{-1}$	2.35 ±1.16	0	3.97			

Note: * SD – standard deviation, PMH – productive machine hour, SMH – scheduled machine hour.

and including delays, respectively), and unloaded travel (6 % and 5 %, by excluding and including delays, respectively); the smallest share was that of maneuvering (2 % and 1 %, by excluding and including delays, respectively).

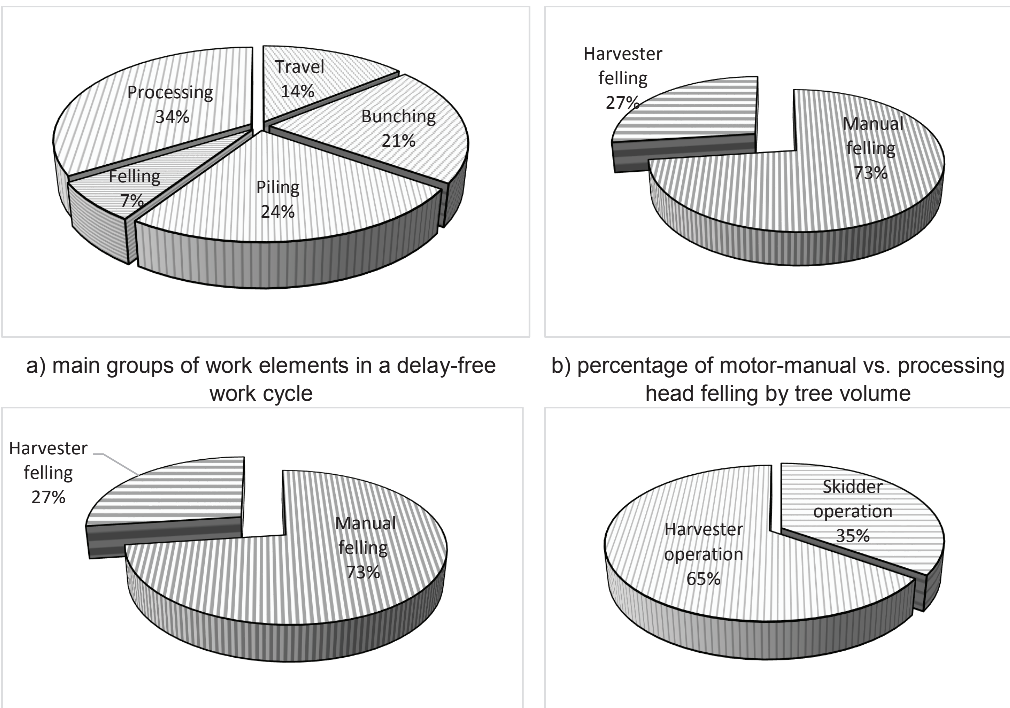
The breakdown of operations in delay-free cycle time by main groups (Fig. 2a) shows the predominance of processing, followed by piling at landing, bunching, travel, and felling trees by harvester head.

During the study 33.2 m^3 of the 124.3 m^3 by volume, and 33 of the 125 felled trees by number respectively were felled by harvester (Fig. 2b, c). The mean time for harvester felling is 114 s per tree (see Table 3).

By time the SH works mostly as harvester and processor (65 %), whereas skidder operations occupy 35 % of its delay-free cycle time (Fig. 2d).

The SH productive time was 89 % from the scheduled time. The delays of 11 % are due to organizational reasons (waiting for the manual felling of trees in the cutting area, personal communications and breaks, phone calls) (7 %), and mechanical delays (4 %).

The regression analysis was performed on the time-study data (Table 3) in order to develop prediction equations for estimating the cycle time of the SH by excluding and including delays both shown in Table 4.



a) main groups of work elements in a delay-free work cycle

b) percentage of motor-manual vs. processing head felling by tree volume

c) percentage of motor-manual vs. harvester head felling by number of the tree felled

d) percentage of skidder vs. harvester operations by time

Fig. 2. Summary statistics of HSM 805 ZL.

Table 4. Summary of the work cycle time models

Equations		*F*	R^2	R^2_{adj}	Std. Error	*p*-Value
$T_{net} = 0.056 \cdot L + 3.70 \cdot V + 5.94 \cdot n_{tr} - 13.73$, min	(1)	69.54	0.93	0.92	3.30	$p < 0.05$
$T = 0.0764 \cdot L$, min	(2)	31.32	0.86	0.83	4.70	$p < 0.05$

The delay-free cycle time T_{net} regression equation containing the significant variables given in equation (1).

In equation (1) the minimum duration of delay-free cycle time T_{net} may be attained in the case of short skidding distances *L*, decreased load volumes *V* and number of trees n_{tr} in a cycle.

The regression equation (2) presents a cycle time including delays *T*.

Consequently, cycle time including delays of the SH depends only on skidding distance *L* and minimum duration may attain in case of minimal skidding distances. Probably, the difference between the two equations could be caused by the effect of included delays which follows different statistical laws (Spinelli and Visser 2008) and, therefore, could mask other important effects (Borz et al. 2014b).

Travel speed and inhaul speed

The mean travel speed of the SH is 1.88 km·h^{-1} (Table 3). The mean speeds with and without load are 1.59 km·h^{-1} and 2.35 km·h^{-1}, respectively. The difference is small – 0.76 km·h^{-1}, due to the fact that loaded travel is downhill, and unloaded travel– uphill, as well as terrain and skid road conditions.

For comparison, Orlovský et al. (2020) found mean speeds with and without load at 5.27 km·h^{-1} and 4.67 km·h^{-1}, respectively, for HSM 805HD four-wheel cable skidder with knuckle-boom with round wood grapple, which were much higher than the studied SH. However, Spinelli and Magagnotti (2012) reported empty and loaded travel speeds of 96 kW agricultural tractor at 8.1 km·h^{-1} and 7.3 km·h^{-1}, respectively, which were significantly higher than those determined in this study. The average speed of John Deere 548H was higher: for unloaded travel was 8.58 km·h^{-1}, whereas for loaded travel, the average speed – 6.02 km·h^{-1} (Proto et al. 2018). The higher speeds mentioned above may be the result of a better prepared skid road surface.

Theoretically, the movement time of a cable skidder could be reduced by increasing the travel speed loaded and unloaded. Unfortunately, the terrain conditions practically do not allow significant increase in travel speed.

The mean speed of a cycle load during winching was 0.09 m·s^{-1} (0.324 km·h^{-1}).

The mean duration of winching operations is long due to extraction of 1–2 trees at once with the winch line. Actually, this is because the worker does not use chokers to attach trees to a winch line.

Productivity analysis

The mean productivity of the SH obtained at mean skidding distance of 69 m, mean bunching distance of 14 m, mean load volume of 4.06 m^3 and 4.07 mean number of trees per cycle (turn) is 9.38 m^3·PMH^{-1} and 8.27 m^3·SMH^{-1}, respectively (Table 3). These productivity rates are not remarkable, comparing the results reported only for skidding operations, but they have also included harvester operations, i.e. these are the rates of timber piled at landing. For comparison, Orlovský et al. (2020) found that HSM 805HD four-wheel cable skidder with knuckle-boom and round wood grapple (winching distance of 8.8 m, skidding distance of 87 m, and a load volume of 3.02 m^3) the net and gross production rates were similar (4.69 $m^3 \cdot h^{-1}$ and 3.33 $m^3 \cdot h^{-1}$, respectively).

Delay-free productivity of the SH was defined by the regression equation (3) shown in Table 5. From equation (3), to increase delay-free productivity of the SH, skidding distance *L* and number of skidded trees n_{tr} should be reduced.

Table 5. Summary of the productivity models.

Equations	*F*	R^2	R^2_{adj}	Std. Error	*p*-Value
$P_{PMH} = 14.59\text{-}0.018 \cdot L\text{-}2.16\ n_{tr}$, $m^3 \cdot h^{-1}$ (3)	6.50	0.57	0.49	1.08	$p < 0.05$
$P_{SMH} = 12.21\text{-}0.029 \cdot L$, $m^3.h^{-1}$ (4)	2.98	0.37	0.25	1.51	$p < 0.05$

From equation (4) shown in Table 5, it can be seen that productivity including delays depends moderately on skidding distance *L*, which should be reduced for better output rates of the SH. This form of the equation may be the effect of including the delays which are known to follow different statistical laws (Spinelli and Visser 2008) and, therefore, to mask other important effects (Borz et al. 2014b).

Cost analysis

Cost calculations were based on the assumption that companies worked all year round with the exception of adverse weather conditions (heavy rain, deep snow, thick fog), when cutting areas are not normally accessible by a wheel skidder.

The hourly fixed operating (variable) costs of the studied SH, and the labor cost of the operator and a chainsaw operator are shown in Table 6 and Figure 3. The gross costs for HSM 805 ZL team were calculated at 132.97 € per productive machine hour (PMH). Thus, when the SH was productive, the cost was at 14.24 €·m^{-3}. The increase in productive time of the SH would lead to decrease in gross costs.

In the distribution of the net costs (Fig. 3), fixed costs predominate; they are more than two times higher than the variable costs and about six times higher than the labor costs. Generally, the fixed cost is around ⅔ of the net cost due to high rate of purchase cost of the SH.

The SH is about 2 times more productive than a logging team of 4–5 people with an adapted agricultural tractor for skidding.

Table 6. Characteristics of costs of the studied skidder.

Costs	Costs per PMH, €	Costs, €·m^{-3}
Fixed costs	70.36	7.50
Variable costs	28.36	3.11
Labor costs	11.94	1.27
Net costs (excluding profit)	110.93	11.88
Overheads and management costs	9.95	1.06
Profit	12.09	1.29
Gross costs (including profit)	132.97	14.24

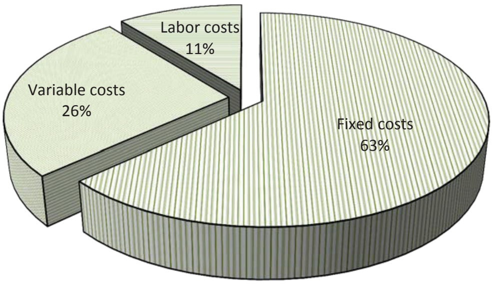


Fig. 3. Percentage distribution of net costs.

When operating in deciduous stands, the harvester unit can be used for felling and cutting the self-pruned part of the tree trunk, especially in soft deciduous tree species. The knuckle-boom can be completely dismantled or the harvester head can be replaced with a log grapple for sorting and piling.

The disadvantage of the SH is that the harvester unit changes the load distribution between drive axles, increasing that of the rear axle. The increased load on the rear axle can result in deep rutting and high soil compaction.

The productivity of a SH could be increased by using chockers for collecting more trees within the same winching cycle. Currently, chokers are not used to attach trees to the winch line and trees are pulled out one by one to the SH, which results in longer bunching time.

Given the average load volume of 4.06 m^3, it can be concluded that the tractive (drawbar) force of the machine is not fully used.

The SH harvesting cost (14.24 €·m^{-3}) fits well within the regional harvesting rates for coniferous stands, which range between 13.50 and 15.00 €·m^{-3}.

Consequently, the combined skidder-harvester is highly productive and cost-effective, compared to the traditional motor-manual technique used today. The use of this type of machine is recommended because it allows to overcome the persistent labor shortage in the logging industry.

Conclusions

The combined machine works as a harvester and it can fell the accessible trees located around the skid road and the corridor. The remaining marked trees in the midst of the stand are felled by chainsaw. Felled trees are pulled to the skid road using the two-drum winch with remote control, and then they are skidded to the landing, where they are delimbed, bucked and piled.

The SH is about two times more productive than a logging team of 4–5 people using chainsaws and an adapted agricultural tractor for felling, processing and skidding the trees.

The productivity of the SH could be increased by using chockers for collecting more trees within the same winching cycle. Currently, chokers are not used to attach trees to the winch line and trees are pulled one by one, which reflects in increased bunching time.

Harvesting cost per unit of the SH is within the range spanned by regional harvesting rates for coniferous stands.

The disadvantage of the SH is that the harvester unit changes the load distribution between the drive axles, increasing the load on the rear axle and causing deep rutting and heavy soil compaction.

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