Evaluation of the Feller-Buncher Moipu 400E for Energy Wood Harvesting

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Abstract – Nacrtak

Proper tending operations in young stands increase the quality of valuable roundwood and reduce the risk of stand damages caused by wind and snow-breaks, and infestation of bark beetles. When felling and extracting small diameter trees, costs often exceed the potential revenues. Mechanized thinning performed by using a forwarder mounted feller-buncher head could improve this cost-effectiveness.

A time study was carried out in a 35–40 year old Scots Pine–Oak dominated stand. Productivity and costs were investigated of a Timberjack 1110D forwarder equipped with the felling-bunching head Moipu 400E. Further objectives were to give practical recommendations for the system in the field.

The harvesting productivity was 4.11 m^3/PSH_0 (effective working hour) or 3.16 m^3/PSH_{15} with an average tree volume of 0.057 m^3, an average load volume of 3.71 m^3, and the average forwarding distance 89 m.

The supply costs from forest to plant (felling, forwarding, chipping, and transportation) were 91.60 €/PSH_{15} or 77.84 € per oven dry ton. In Austria it is possible to achieve revenues of 78.00 € per oven dry ton. Therefore it is possible to gain profit.

The feller-buncher head Moipu 400E is best suited to cut Pine trees up to a maximum diameter at the butt of about 30 cm, and Oak and Beech up to 25 cm. In order to keep the felling-bunching costs at a reasonable level, mechanized harvesting should be done at sites where the average volume of removed trees is over 0.05 m^3 per tree.

Keywords: energy wood harvesting, thinning, felling head Moipu 400E, productivity, costs

1. Introduction – *Uvod*

Careful management and proper tending operations in young stands increase the quality of valuable roundwood and reduce the risk of stand damages caused by wind and snow-breaks, and infestation of bark beetles. According to the Austrian Forest Inventory (Österreichische Waldinventur 2004) there was a decline in tending and thinning operations. There is a potential amounting to 64 million m^3 over bark available for thinning. Eberhardinger (2007) also describes a decrease in thinning utilisation in Germany.

During the 1990s harvesting in Central Europe underwent considerable development by introducing the highly mechanized harvester technology. Particularly when harvesting small-sized trees, harvesters have higher efficiencies than chainsaws used for felling and processing. Nevertheless it is difficult to achieve a positive contribution margin in first thinnings, because of higher harvesting costs and lower price for small-diameter timber (Affenzeller and Stampfer 2007).

Another option to make use of the biomass that accrues in precommercial thinning is chipping to biomass fuel for power plants. Delimbing and bucking is not necessary to obtain energy wood, therefore simple feller-buncher heads without feed rollers and delimbing knives can be used instead of expensive harvester heads. Several felling heads are available for harvesting only energy wood. These heads can be mounted on forwarders or tractors. The head can be constructed for single tree handling or felling and accumulating trees. Thereby it is possible to handle several trees during one crane cycle.

A number of studies have been carried out on the new biomass harvesting technology. Spinelli et al. (2006) and Eberhardinger (2007) analyzed feller-bunchers for energy wood harvesting whereby felling was separated from extraction. Laitila and Asikainen (2006) examined a conventional forwarder equipped with the Moipu 400 E energy wood head that performed felling and extracting continuously. Kärhä (2006) compared the two-machine (harvester and forwarder) concept with the integrated system. Affenzeller and Stampfer (2007) examined single-tree felling, loading and extraction with tractor trailer equipped with a crane, as a continuous process.

As mentioned above there already exists an evaluation of the energy wood head Moipu 400E which was conducted in Finland (Laitlila and Asikainen 2006). This study was carried out on either birch or pine dominated stands. When cutting trees of an average of 0.045 m^3, the productivity was about 3.5 m^3/PSH_0. In the study by Affenzeller and Stampfer (2007), a productivity of only 1.6 m^3/PSH_0 was achieved with a tractor-trailer combination in Pine stands for trees of comparable size. This is less than half of the productivity attained with the felling-bunching head Moipu 400E. At present there are no studies about Moipu 400E under Central European conditions. The influence of different tree species on productivity of the felling machine was never evaluated. For the efficiency of a tending operation not only the productivity level, but also the revenues and costs are important. Forest enterprises are focused on cost covering tending operations, and without that coverage necessary stand treatments are neglected.

This investigation evaluates the influence of stand and terrain parameters on productivity and costs of a forwarder, equipped with the feller-buncher head Moipu 400E. The experiment was carried out in a Scots Pine and Oak dominated stand.

2. Methodology – *Metodologija*

2.1 Model hypothesis – Hipoteza

Affenzeller and Stampfer (2007) analyzed the productivity of the felling head Naarva Grip 1500-25, Eberhardinger (2007) of Naarva Grip 1500-25E. Laitila and Asikainen studied the productivity of Moipu 400E combined with a forwarder in Finland in 2006. On the basis of these experiments the model hypothesis assumes that productivity is a function of tree volume, tree species, number of trees in a bunch, cutting removal per hectare, forwarding distance, slope, and average tree volume of a load.

The productivity model comprises 7 submodels or terms, respectively:

1. Cutting time
2. Cutting & Loading time
3. Loading time
4. Moving time
5. Forwarding time
6. Unloading time
7. Operational delay time

2.2 Machine description and harvesting system – Opis stroja i sustava pridobivanja drva

The base machine of the feller-buncher was the 8-wheeled Timberjack 1110D forwarder (Fig. 1) with a weight of 14700 kg (load rating 12000 kg).

The Moipu 400E head was mounted on the forwarders crane. It performs cutting, bunching, and

Fig. 1 Timberjack 1110D with Moipu 400E head
Slika 1. *Timberjack 1110D sa sječnom glavom Moipu 400E*

grappling so that one base machine performs the whole process from felling to extraction. The Moipu 400E head uses a single-action shear for cutting. The maximum cutting diameter for single trees is 30 cm and 50 cm for bunches. The opening diameter of the head is 120 cm and it weighs 540 kg (Moisio Forest 2008).

The machine combination uses the following harvesting procedure: First the forwarder drives backwards into the stand and opens a strip road. Trees on the strip road are felled and piled alongside the trail. On the way back out of the stand, the machine loads the processed trees into the load space. The fully loaded forwarder drives to the landing and starts unloading. After unloading, the forwarder drives back to the stand and thins both sides of the strip road beginning at the end of the strip road. Whole-tree harvesting was carried out; trees were extracted with tops and branches. The loaded bunches of trees exceeded the forwarder's load space. Thus the fully loaded forwarder was not capable of driving backwards; therefore a two step procedure was necessary.

2.3 Study site – Mjesto istraživanja

Time studies were carried out in a stand close to Lockenhaus – Austria. The extent of the area was 0.96 ha with an average 7% slope. The dominant height of the 35–40 year old stand was 18 m. The major tree species is Scots Pine (*Pinus sylvestris*) with 50% of the stand's volume; followed by Sessile Oak (*Quercus petraea*) with 40% of the stand's volume. Beech (*Fagus sylvatica*) and Larch (*Larix decidua*) are less numerous. Oak trees originate partly from coppicing and to some extent from generative regeneration. Stand density was reduced from over 4700 stems per hectare to an average of 1800 stems per hectare. The average tree volume of removed trees was 0.057 m^3. The harvested volume was 170 m^3/ha.

2.4 Data collection – Prikupljanje podataka

The time study was carried out by means of the continuous time method with the use of the field computer Latschbacher EG 20. The work of the energy wood harvesting system was divided into elements with clearly recognizable starting and ending points (Table 1).

The variables, covariates and the factor with two levels are shown in Table 2.

A mixed stand was examined in order to figure out the effect of the factor tree species. In the stand 5 skid roads with a corridor spacing of 16 m were marked with paint. The skid roads were divided into sections of 20 m in distance. Thus plots were established of 320 m^2 in size as reference unit for the observation of terrain and stand conditions (slope, cutting removal per ha).

In the volume inventory the diameter at breast height (DBH) of each tree was measured with a calliper in order to use these data for calculating dry mass and volume, respectively. The diameters were grouped in DBH-classes and marked with a colour-code according to Affenzeller and Stampfer (2007). The tree volume was calculated using biomass models of Zianis et al. (2005). To achieve the volume in m^3, the dry weight (kg) of the trees is divided by the oven-dry density (kg/m^3). The oven-dry densities of different tree species are published in ÖNORM B 3012 (2003).

2.5 Statistical analyses – Statistička analiza

Variance analysis attempts to quantify the influence of nominal or ordinal-scaled variables. The statistical analysis was carried out with the computer software SPSS 15.0 for Windows, the statistical fundamentals as described in Stampfer (2002). For each part of the model, the following analysis strategy was chosen:

⇒ develop a linear model with all co-variables and factors,

⇒ evaluate non-linearity of co-variables,

⇒ choose a number of sub-models through removal of non-significant variables,

⇒ choose two-ways interactions of sub-models.

Tree volume is a major part of all production functions but the relationship between productivity and tree volume is rarely linear. Therefore a power factor is used on the co-variable tree volume. Häberle (1984) recommends the estimation of this power value with an iterative procedure aimed at optimizing the coefficient of determination and the distribution of residues.

2.6 Cost analyses – Analiza troška

The calculation of the machine rates was conducted with a few modifications according to the Scheme of Food and Agriculture Organization of the United Nations (FAO 1992). The fixed costs comprise costs for interest, depreciation, and storage and insurance. The purchase price for the forwarder and the crane mounted felling head was 260,750 €, and the costs for storage and insurance were 475 € per year (Renner 2008. The annual interest costs were calculated at an interest rate of 4.5%. The depreciation was calculated assuming an economic life of 6 years. All calculations were done underlying 1500 scheduled system hours per year (PSH_{15}) and an expected useful

Table 1 Time study elements
Tablica 1. *Radne sastavnice*

Element *Radna sastavnica*	Description *Opis*	Unit *Jedinica*
Cutting *Sječa*	Start: Head is in horizontal position for cutting – *Početak: Sječna je glava u vodoravnom položaju za sječu* End: New cycle, or another element starts – *Kraj: Novi ciklus ili početak druge radne sastavnice*	min
Cutting & Loading *Sječa s utovarom*	Start: Head is in horizontal position for cutting – *Početak: Sječna je glava u vodoravnom položaju za sječu* End: New cycle, or another element starts – *Kraj: Novi ciklus ili početak druge radne sastavnice*	min
Loading *Utovar*	Start: Head is in vertical position for loading – *Početak: Sječna je glava u uspravnom položaju za utovar drva* End: New cycle, or another element starts – *Kraj: Novi ciklus ili početak druge radne sastavnice*	min
Moving *Premještanje*	Start: Wheels are rotating after Cutting, Cutting & Loading, or Loading *Početak: Pokretanje kotača nakon sječe, sječe s utovarom ili utovara* End: New element starts – *Kraj: Početak druge radne sastavnice*	min
Driving loaded *Opterećeno kretanje*	Start: Wheels are rotating and load space is completely loaded *Početak: Pokretanje kotača, a utovarni je prostor potpuno natovaren* End: New element starts – *Kraj: Početak druge radne sastavnice*	min
Unloading *Istovar*	Start: Crane starts unloading on landing – *Početak: Dizalica počinje istovar na stovarištu* End: New element starts –*Kraj: Početak druge radne sastavnice*	min
Driving unloaded *Neopterećeno kretanje*	Start: Wheels are rotating after Unloading – *Početak: Pokretanje kotača nakon istovara* End: New element starts – *Kraj: Početak druge radne sastavnice*	min
Down-time <15 *Kvarovi i popravci <15*	Machine down-time shorter than 15 minutes *Kvarovi i popravci kraći od 15 minuta*	min
Down-time >15 *Kvarovi i popravci >15*	Machine down-time longer than 15 minutes *Kvarovi i popravci dulji od 15 minuta*	min
Operational delay time *Povremeni radovi*	Delays related to thinning (e.g. clearance of already cut trees) *Prekidi povezani s proredom (npr. čišćenje već posječenih stabala)*	min
Miscellaneous Preostali prekidi rada	Other delays *Ostali prekidi rada*	min

life of 10,000 PSH_{15}. The operating costs comprise maintenance and repair, fuel costs, and costs for lubricants. The maintenance and repair rate was set at 0.8. The fuel consumption rate was 10 liters/hour. The lubricants costs are assumed to be 25% of the fuel costs, underlying a fuel price of 1.17 €/litre. The labour costs including wages account for 25 €/PSH_{15}. All calculations are made without sales tax.

3. Results – *Rezultati*

3.1 Distribution of time consumption – *Raspodjela utroška vremena*

Felling & loading and Loading (elements *cutting, cutting & loading, and loading*) represented 50% of total time consumption (Fig. 2). Time consumption for forwarding was 3% when loaded and 4% when empty. This is the case because the distance between landing and loading the first time was longer than the distance between loading the last time and the landing. Moving during cutting and loading and unloading at the landing were both 6% of total time consumption. 8% of the time was used for manipulation. Down-time shorter than 15 minutes represented 12%, and down-time longer than 15 minutes 11% of the recorded total time. Down-times were the result of time for breaks and repairs.

1104 cycles (bunches) for cutting and cutting & loading were recorded. The average number of trees in a bunch was 2.6 trees. The average diameter at breast height of removed trees was 9.23 cm. 44 loads with a total volume of 163 m^3 were recorded. Total average forwarding distance was 89 m. The average volume of a load was 3.7 solid m^3.

3.2 Productivity functions – *Funkcije proizvodnosti*

Equation 1 shows the productivity for the entire harvesting system. Sub-models were used because of the different number of cycles for sub-models ac-

Table 2 Variables, Factor, and Covariates of the productivity model
Tablica 2. *Nezavisne i zavisne varijable te faktor modela proizvodnosti*

Type *Vrsta*	Name *Ime*	Description *Opis*
Dependent Variables *Zavisna varijabla*	Cutting time – t_{cut}, min/cycle *Sječa* – t_{cut}, min/tura	Total time for cutting trees, Productive system hour *Ukupno vrijeme sječe stabala, pogonski sat rada*
	Cutting & Loading time – $t_{cut\&load}$, min/cycle *Sječa s utovarom* – $t_{cut\&load}$, min/tura	Total time for cutting and loading trees, Productive system hour *Ukupno vrijeme sječe i utovara stabala, pogonski sat rada*
	Forwarding time – t_{for}, min/cycle Izvoženje drva – t_{for}, min/tura	Total time for driving loaded and unloaded; Productive system hour *Ukupno vrijeme kretanja opterećenoga i neopterećenoga vozila, pogonski sat rada*
	Moving time – t_{mov}, min/cycle *Premještanje* – t_{mov}, min/tura	Total time for moving between cutting & loading, Productive system hour *Ukupno vrijeme premještanja između sječe i utovara, pogonski sat rada*
	Loading time – t_{unload}, min/cycle *Utovar* – t_{unload}, min/tura	Total time for loading, Productive system hour *Ukupno vrijeme utovara, pogonski sat rada*
	Unloading time – t_{load}, min/cycle *Istovar* – t_{load}, min/tura	Total time for unloading of a load, Productive system hour *Ukupno vrijeme istovara tereta, pogonski sat rada*
Factor *Faktor*	Tree Species, 2 Levels *Vrsta drveća, 2 razreda*	Scots Pine (0), Oak (1) *Obični bor (0), hrast (1)*
Covariates *Nezavisna varijabla*	Tree volume – V_{tree}, m^3 over bark *Obujam stabla* – V_{tree}, m^3 *s korom*	Average tree volume *Prosječni obujam stabla*
	No. of trees in a bunch, *n* *Broj stabala u svežnju, n*	Number of trees in a bunch *Broj stabala u svežnju (zahvatu)*
	Cutting removal, m^3 over bark/ha *Sječna gustoća*, m^3 (*s korom*)/ha	Timber removal quantity per ha *Količina posječenoga drva po ha*
	Forwarding distance – *dist*, m *Udaljenost izvoženja – dist*, m	Forwarding distance of a load (average of driving loaded and unloaded) *Prosječna udaljenost kretanja neopterećenoga i opterećenoga vozila*
	Load volume – *load*, m^3 over bark *Obujam tovara – load*, m^3 *s korom*	Volume of a load *Obujam utovarenoga tereta*
	Slope, % *Nagib terena*, %	Gradient of slope *Kut nagiba terena*
	Average tree volume of load, m^3 over bark *Prosječan obujam stabla u tovaru*, m^3 s korom	Average tree volume of a load *Prosječan obujam stabla u tovaru vozila*

$$PROD = \frac{60}{k_1 \cdot \left[\left(t_{cut} + t_{load} \right) \cdot \frac{V_{cut}}{V_{tot}} + t_{cut\&load} \cdot \frac{V_{cut\&load}}{V_{tot}} + t_{for} + t_{mov} + t_{unload} + t_{od} \right]} \quad (1)$$

where:

- $PROD$ Productivity of the forwarder equipped with Moipu 400E head m^3/PSH$_{15}$
- k_1 Conversion factor from PSH$_0$ to PSH$_{15}$
- t_{cut} Cutting time, min/m^3
- t_{load} Loading time, min/m^3
- $t_{cut\&load}$ Cutting & loading time, min/m^3
- t_{for} Forwarding time, min/m^3
- t_{mov} Moving time, min/m^3
- t_{unload} Unloading time, min/m^3
- t_{od} Operational delay time, min/m^3
- V_{cut} Volume that was first cut and then loaded, m^3
- $V_{cut\&load}$ Volume that was cut and loaded subsequently, m^3
- V_{tot} Total harvested volume, m^3

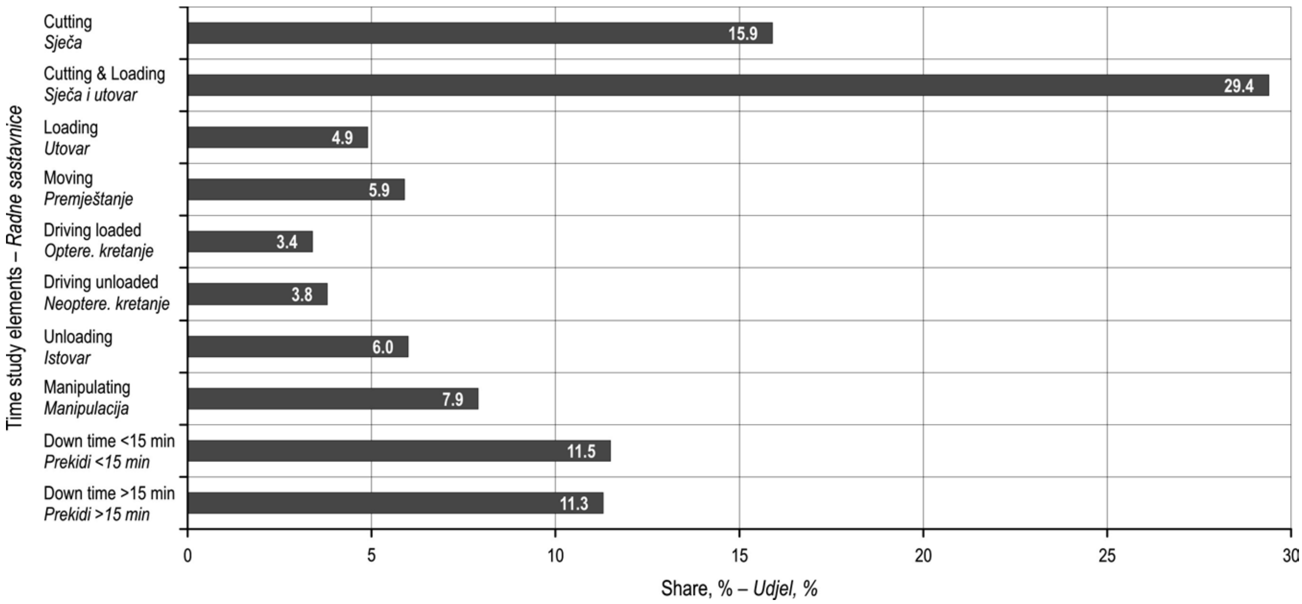

Fig. 2 Structure of time consumption
Slika 2. *Struktura utroška vremena*

Table 3 Means, 5% and 95% Quantile of covariates
Tablica 3. *Aritmetičke sredine te 5. i 95. percentili nezavisnih varijabli*

Covariate *Nezavisne varijable*	Mean *Aritmetička sredina*	$Quantile_5$ *5. percentil*	$Quantile_{95}$ *95. percentil*
Tree volume, m^3 *Obujam stabla*, m^3	0.057	0.012	0.212
Volume of load, m^3 *Obujam tovara*, m^3	3.71	1.13	5.61
Forwarding distance, m *Udaljenost privlačenja*, m	88.8	22.0	175.6
Slope, % *Nagib*, %	6.9	5.0	10.3
Number of trees in a bunch, n *Broj stabala u zahvatu, n*	2.6	1.0	8.0

cording to their reference unit (bunch of trees, or load). Furthermore the detailed observation of individual working phases increases the accuracy of predictions in the entire productivity model.

Table 3 shows the means, the 5th and 95th percentile of the covariates. For the entire productivity model only the covariates average tree volume, forwarding distance, and load volume were significant.

The assumption that the cutting time depends on the factor tree species, as well as on the covariates number of trees in a bunch, cutting removal/ha and slope could not be verified. The cutting time only depends on the tree volume (Equation 2). The number of trees in a bunch and the tree species were intercorrelated with the tree volume; therefore the number of trees in a bunch was not used in the covariance analysis. The intercorrelation between tree species and tree volume might be caused by biomass models used for different species; therefore the factor tree species was not used in the regression model. To achieve linearity the exponent -0.9 was used in the statistical model.

$$t_{cut} = 2.249 + 0.362 \cdot V_{tree}^{-0.9} \quad R^2 = 0.556 \qquad (2)$$

where:

t_{cut} Cutting time, min/m^3
V_{tree} Average tree volume, m^3

The cutting & loading time depends on the tree volume (Equation 3). The other covariates and the factor tree species had no significant influence on the cutting & loading time per m^3.

$$t_{cut\&load} = 6.774 + 0.267 \cdot V_{tree}^{-0.9} \quad R^2 = 0.275 \qquad (3)$$

where:

$t_{cut\&load}$ Cutting & loading time, min/m^3
V_{tree} Average tree volume, m^3

The time consumption of forwarding (average of driving loaded and unloaded) depends on the forwarding distance (Equation 4). It accounts for 91% of

Table 4 Means, 5% and 95% Quantile of dependent variables
Tablica 4. *Aritmetičke sredine te 5. i 95. percentili zavisnih varijabli*

Dependent variable *Zavisne varijable*	Mean *Aritmetička sredina*	$Quantile_5$ *5. percentil*	$Quantile_{95}$ *95. percentil*
Cutting time – t_{cut}, min/m^3 *Sječa* – t_{cut}, min/m^3	10.22	2.33	25.99
Cutting & Loading time – $t_{cut\&load}$, min/m^3 *Sječa s utovarom* – $t_{cut\&load}$, min/m^3	13.94	4.59	24.80
Forwarding time – t_{for}, min/m^3 Izvoženje drva – t_{for}, min/m^3	0.72	0.31	1.67
Moving time – t_{mov}, min/m^3 *Premještanje* – t_{mov}, min/m^3	1.12*	0.39	1.80
Loading time – t_{unload}, min/m^3 *Utovar* – t_{unload}, min/m^3	1.81*	1.00	2.69
Unloading time – t_{load}, min/m^3 *Istovar* – t_{load}, min/m^3	1.14*	0.79	1.62
Operational delay time – t_{od}, min/m^3 *Povremeni radovi* – t_{od}, min/m^3	1.50*	0.21	3.16

* values used in the productivity model – *vrijednosti korištene u modelu proizvodnosti*

the variance of time consumption for forwarding. The influence of load volume was not significant. The division by the load volume is necessary to achieve min/m^3.

$$t_{\text{for}} = \frac{0.028 \cdot dist}{load} \quad R^2 = 0.91 \tag{4}$$

where:

t_{for} Forwarding time, min/m^3
dist Average of driving loaded and unloaded, m
load Volume of a load, m^3 (over bark)

The time consumption of moving, loading, unloading, and operational delays is very homogenous in each cycle. There is a relatively low variation of processes compared to the other 3 sub-models (Table 4). Therefore the means are used as constant terms. These means are calculated by dividing the respective elemental times (total time for moving, unloading and operational delays) by the total volume harvested. The time of loading was divided by the volume that was loaded. Operational delay time considers time related to thinning (e.g. clearance of already cut trees) that could not be added to another working element. For example after felling a couple of trees, the forwarder had to clear the cut trees before moving. However the clearance of already cut trees failed to appear in each cutting cycle. Thus operational delay time was collected separately from cutting. It was calculated by dividing the entire recorded time for operational delays by the total volume harvested. The constant terms for moving time, loading time, and unloading time, as well as for operational delays are summed up in Table 4.

All sub-models are based upon productive system hours without down-times (PSH_0). In practice down-times of up to 15 minutes are commonly included in the productive machine hours (PSH_{15}) (Stampfer 2002). The factor k_1 derived from the elemental time study was 1.15. However during elemental time collection there were almost no repairs, and also time for maintenance was not recorded. Thus for the forwarder equipped with the Moipu 400E head k_1 was set at 1.3. The average productivity in this study was 4.11 m^3/PSH_0. Using the factor k_1 the attained productivity was 3.16 m^3/PSH_{15}. This is equivalent to 8.85 cubic metre loose/PSH_{15} using a factor of 2.8 (ÖNORM M 7132 1998) to convert cubic metre in cubic metre loose. Fig. 3 shows the productivity of the forwarder equipped with the Moipu 400E head dependent on the tree volume. The three graphs show the range of the model's validity in accordance with the forwarding distance (5th percentile, average, 95th percentile). Fig. 4 also shows the system productivity, but underlying the range of the model's validity using the 5th and 95th percentile, as well as the average, of the forwarder's load volume.

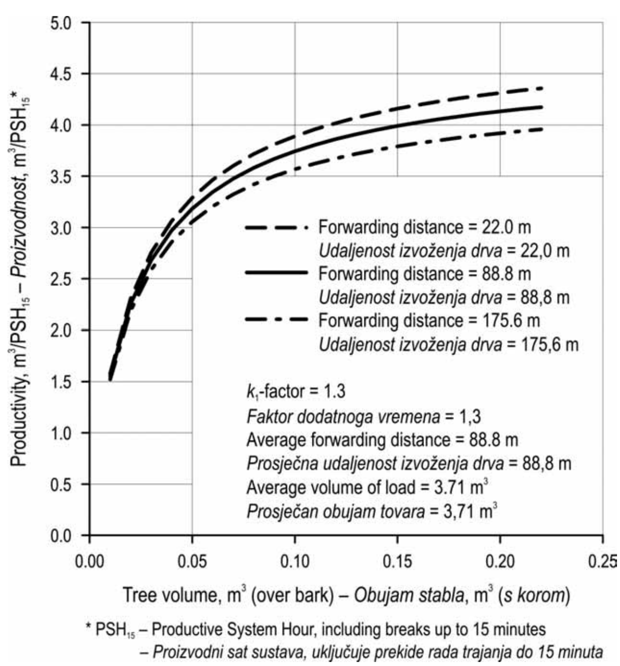

Fig. 3 Productivity model for the machine system (validity of forwarding distance)
Slika 3. *Pouzdanost modela proizvodnosti istraživanoga sustava (udaljenost izvoženja drva)*

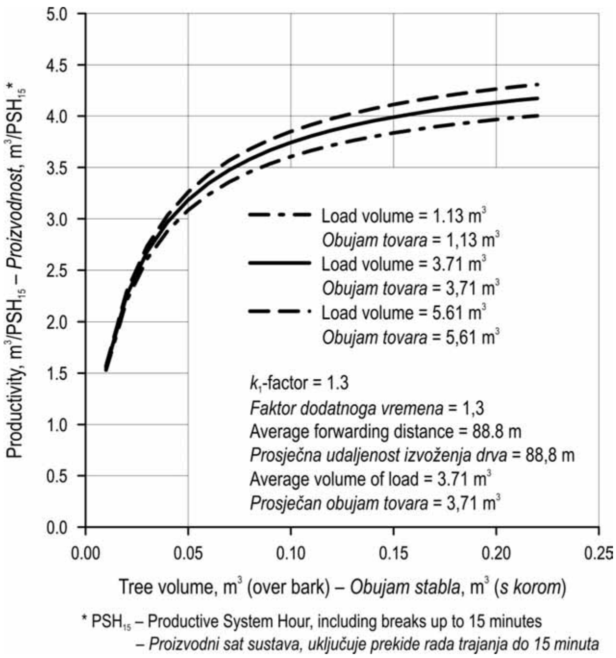

Fig. 4 Productivity model for the machine system (validity of load volume)
Slika 4. *Pouzdanost modela proizvodnosti istraživanoga sustava (obujam tovara)*

3.3 Costs – *Troškovi*

The system costs (net value) of the harvesting system are 91.60 €/PSH_{15}. The fixed costs account for 33.20 €/PSH_{15}, and are at the same level as the operating costs of 33.40 €/PSH_{15}. The labour costs are 25.00 €/PSH_{15}. The average productivity is 3.16 m^3/PSH_{15}, and therefore the total costs for felling and forwarding are 28.99 €/m^3. The factor 2.8 was used to convert cubic metre in cubic metre loose (ÖNORM M 7132, 1998).

The costs for chipping 3.1 €/cubic metre loose found by Affenzeller and Stampfer (2007) in their study results is 8.68 €/m^3. According to Ganz et al. (2005) the costs for transportation range between 2.3 and 3.3 €/cubic metre loose. In this study the costs for transportation were calculated with 2.9 €/cubic metre loose or 8.12 €/m^3. The total costs of felling and forwarding, chipping, and transportation add up to 45.79 €/m^3 (16.35 € per cubic metre loose). Overhead expenses for bookkeeping and communications, as well as office expenses are not included in the calculation. Entrepreneurial profit and moving expenses are also excluded from this calculation.

The costs of 45.79 €/m^3 are equivalent to 77.84 € per oven dry ton. Using the oven dry densities for Pine, Oak, Beech and Larch (ÖNORM B 3012, 2003) weighted by their rate on the total volume, which results in 587 kg/m^3, the conversion factor was 1.70. Assuming a price of 78.00 € per ton of oven dry chips (Österreichische Forstzeitung, 2008), results in a slightly positive contribution margin.

4. Discussion – *Rasprava*

The variables tree volume and forwarding distance have the major influence on productivity of the entire system. The factor tree species had no significant impact. The productivity of the Moipu 400E energy wood head mounted on a forwarder is 4.11 m^3/PSH_0 or 3.16 m^3/PSH_{15}. That is even higher than the productivity for comparable tree volume found by Laitila and Asikainen (2006) who obtained 3.75 m^3/PSH_0.

In consideration of the costs of harvesting, chipping, and transportation of energy wood, compared with the prices achieved for energy wood, a positive contribution margin is possible. The costs for felling, forwarding, chipping, and transportation add up to 77.84 € per oven dry ton. Assuming a price of 78.00 € per oven dry ton of chips, there was a slightly positive contribution margin. However this calculation does not consider overhead expenses for bookkeeping and communications, as well as office expenses and entrepreneurial profit and moving expenses. To gain profit the timber contractor will set the price for his logging job at a higher level, which means higher energy wood harvesting costs. This would result in a negative contribution margin for the forest owner. In the economic sense of cost-accounting it must be calculated as investment costs in silvicultural tending activities with the objective of obtaining saw timber.

Nevertheless, compared to an earlier study examining a similar felling device, the Moipu 400E proved to be efficient and competitive. Affenzeller and Stampfer (2007) examined single-tree felling, loading and extraction with tractor trailer equipped with a crane, as a continuous process. The felling device mounted on the crane was the Naarva Grip 1500-25, a felling head that is not capable of bunching trees. Affenzeller and Stampfer achieved a productivity of just 1.33 m^3/PSH_{15} (1.60 m^3/PSH_0). They figured out that productivity of their fully mechanized system failed to cover the rate of fixed costs that arise in the mechanized system. The total costs of harvesting, extraction, chipping, and transportation to the biomass power plant were 21.20 €/cubic metre loose. In this study the total costs for the supply of chips are 16.35 € per cubic metre loose. When harvesting an average tree volume of 0.045 m^3, as in the Naarva Grip 1500-25 study, the costs increase to 16.62 € per cubic metre loose. Nevertheless this leads to a cost decrease of 4.58 € per cubic metre loose.

Kärhä (2006) compared the whole-tree harvesting system carried out with 4 forwarders equipped with felling heads and with 5 different harvesters combined with forwarders. The productivity of the forwarder equipped with a felling head was 4.6–5 m^3/PSH_0 when harvesting trees with an average volume of 0.057 m^3 at a forwarding distance of 250 m. This is somewhat better than in this study (4.11 m^3/PSH_0). The costs per productive system hour for the two machine system were approximately 70% higher than the one machine system costs. However, the difference in productivity of the two systems does not result in dramatically different harvesting costs per m^3.

Laitila (2008) found that the two machine system (harvester with an accumulating felling head, and forwarder) was more cost competitive than the one machine (forwarder and felling head) system. The costs of the forwarder equipped with a felling head were 3.9 €/m^3 higher than the costs of the logging system based on a harvester. The difference must be caused by differences in forwarding time. (The head mounted on the harvester and forwarder was the same.) With the conventional forwarder the average grapple load size in unloading was 0.6 m^3 whilst the average grapple load size of the felling head used as grapple was just 0.3 m^3. Laitila assumes that the explanation for this significant difference is the structure of the felling head grapple. It is designed not just for loading but also for cutting. Thus the compromise grapple is not as efficient as the purpose-built timber grapple.

A new attempt to gain profit in thinning operations when using feller-bunchers could be the integrated harvesting of energy wood for chipping and roundwood. Therefore the feller-buncher should be capable of delimbing the trees. The prototype of a modified Moipu head with delimbing capability is already available on the market. Scandinavian machine manufactures developed in the past the so-called multitree handling machine, which could process and delimb 2 trees at the same time. The problem considering roundwood production was the delimbing and bucking quality. However these requirements are not important for energy wood production. Thus this machine could get a revival.

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Sažetak

Ocjena višezahvatne sječne glave Moipu 400E pri pridobivanju drva za energiju

Pravilna njega mladih sastojina povećava kakvoću vrijednoga drva i smanjuje opasnost od oštećivanja sastojina vjetrolomima, snjegolomima te gradacijom potkornjaka. Pri pridobivanju drva iz pretkomercijalnih proreda troškovi često nadilaze mogući prihod zbog niske vrijednosti drva malih dimenzija. Jedna je od mogućnosti upotrebe sitnoga drva iz pretkomercijalnih proreda usitnjavanje stabala u iverje, koje se rabi kao gorivo u bioenerganama. Kresanje grana i trupljenje debla nije nužno pri pridobivanju šumske biomase te se stoga umjesto skupih harvesterskih glava mogu rabiti jednostavne višezahvatne sječne glave bez posmičnih valjaka i noževa za kresanje grana. Strojno prorjeđivanje uporabom forvardera s ugrađenom višezahvatnom sječnom glavom može poboljšati djelotvornost u pretkomercijalnim proredama zbog zahvatanja i sječe više tanjih stabala u jednom radnom hodu dizalice.

Cilj je ovoga istraživanja vrednovanje utjecaja sastojinskih i terenskih čimbenika na proizvodnost i troškove rada osmokotačnoga forvardera Timberjack 1110D (mase 14,7 t te dopuštene nosivosti 12 t) na čiju je dizalicu (umjesto hvatala) ugrađena višezahvatna sječna glava Moipu 400E pri pridobivanju energentskoga drva (slika 1). Sječna glava siječe, skuplja i zahvaća stabla te tako jedno vozilo siječe, ali i privlači drvo. Sječna glava Moipu 400E teška je 540 kg, ima škare za sječu, najveći radni promjer pri sječi pojedinačnih stabala je 30 cm, a 50 cm pri sječi svežnja stabala.

Pri izračunu troškova strojnoga rada primijenjena je modificirana metodologija FAO-a (1992). Fiksni troškovi obuhvaćaju amortizaciju stroja, kamate za investiciju te troškove osiguranja i garažiranja. Nabavna cijena forvardera s dizalicom te ugrađenom sječnom glavom iznosi 260 750 EUR, a godišnji trošak garažiranja i osiguranja 475 EUR. Godišnji trošak vezan uz nabavu stroja zasnovan je na kamati od 4,5 %. Amortizacija je temeljena na vremenu zastarijevanja stroja od 6 godina. Svi su izračuni zasnovani na 1500 pogonskih sati rada godišnje, odnosno 10 000 pogonskih sati rada u normalnom uporabnom razdoblju. Varijabilni troškovi obuhvaćaju održavanje i popravke stroja te troškove goriva i maziva. Trošak održavanja i popravaka iznosi 80 % amortizacije, a potrošnja goriva 10 L po satu rada. Trošak maziva pretpostavlja 25 % troška goriva, čija je jedinična cijena 1,17 EUR/L. Trošak radnika obuhvaća njegovu plaću u iznosu od 25 EUR po pogonskom satu rada stroja. Svi izračuni su bez PDV-a. Na osnovi navedenih ulaznih podataka fiksni troškovi iznose 33,2 EUR, varijabilni 33,4 EUR, a trošak radnika 25 EUR, što ukupno daje trošak sječe i izvoženja drva u iznosu od 91,6 EUR po pogonskom satu rada.

Za istraživanje je odabrana mješovita sastojina običnoga bora i hrasta kitnjaka zbog utvrđivanja utjecaja vrste drveća na razinu proizvodnosti opisanoga stroja. Istraživanje je provedeno u odjelu površine 0,96 ha, prosječna nagiba terena od 7 %. Sastojina je u dobi između 35 i 40 godina, s dominantnom visinom od 18 m. U drvnoj zalihi bijeli bor sudjeluje s 50 %, hrast kitnjak s 40 %, a obična bukva i europski ariš pridolaze u primjesi. Kitnjakova stabla djelomično potječu iz panja, odnosno iz sjemena. Proredom je gustoća sastojine smanjena s 4700 stabala/ha na 1800 stabala/ha. Sječna je gustoća iznosila 170 m^3/ha, a prosječni obujam posječenoga stabla 0,057 m^3.

Tijekom rada istraživani je stroj radio na sljedeći način. Na početku, krećući se unazad, vozilo ulazi u sječinu, pri čemu si otvara vlaku. Stabla na trasi vlake siječe i uhrpava uz njezin rub. Pri povratku iz sječine vozilo tovari posječena i uhrpana stabla u svoj utovarni prostor, te završetkom utovara nastavlja se kretati prema pomoćnomu

stovarištu, gdje započinje s istovarom. Pri ponovnom vraćanju u sječinu počinje prorjeđivati sastojinu s obje strane, i to s kraja prethodno prosječene vlake. Pri radu se rabi stablovna metoda izradbe drva, tako da se posječena stabla privlače zajedno s ovršinama i granama. Utovareni svežnjevi stabala, obujamno (ali ne maseno) nadilaze mogućnosti utovarnoga prostora vozila. Tako natovareno vozilo nije se u mogućnosti kretati unazad prema pomoćnomu stovarištu, te je stoga prijeko potreban opisani način rada, tj. u dva koraka.

Za potrebe istraživanja bojom je označeno 5 traktorskih vlaka međusobna razmaka 16 m. Traktorske su vlake razdijeljene po duljini na segmente od 20 m te su tako oblikovane plohe površine 320 m^2, na kojima su prikupljani podaci o terenskim i sastojinskim čimbenicima (nagib terena, sječna gustoća i dr.). Prsni su promjeri stabala mjereni s promjerkom, a za utvrđivanje biomase stabala korišten je model koji su dali Zianis i dr. (2005). Obujam i masa suhe tvari utvrđeni su pomoću pretvorbenih koeficijenata za različite vrste drveća (ÖNORM B 3012, 2003).

Studij rada i vremena proveden je protočnom metodom kronometrije i primjenom terenskoga računala Latschbacher EG 20. Radni proces pridobivanja drva za energiju razdijeljen je u radne sastavnice s jasno određenim fiksažnim točkama (tablica 1).

Hipoteza istraživanja pretpostavlja da je proizvodnost opisanoga stroja funkcija obujma stabla, vrste drveća, broja stabala u zahvatu sječne glave, sječne gustoće, udaljenosti privlačenja drva, nagiba terena i prosječnoga obujma stabla u tovaru vozila. Model se proizvodnosti sastoji od sedam podmodela utrošaka vremena, i to: 1) sječe, 2) sječe i utovara, 3) utovara, 4) premještanja, 5) izvoženja, 6) istovara, 7) povremenih radova. Nezavisne i zavisne varijable te faktor u modelu proizvodnosti prikazani su u tablici 2.

Analizom varijance nastojao se kvantificirati utjecaj nominalnih i ordinalnih varijabli. Statistička je analiza provedena uz pomoć računalnoga programa SPSS 15.0. Analiza svakoga pojedinoga podmodela provedena je po sljedećoj strategiji:

⇒ *razvoj linearnoga modela sa svim nezavisnim varijablama i faktorima*

⇒ *ocjena nelinearnosti nezavisnih varijabli*

⇒ *izbor broja podmodela izbacivanjem statistički neznačajnih varijabli*

⇒ *izbor dvostruke interakcije podmodela.*

Tijekom istraživanja ostvarena su 1104 ciklusa zahvatanja svežnja stabala pri sječi, odnosno pri sječi i utovaru. Prosječan broj stabala u svežnju iznosio je 2,6, a prosječan prsni promjer posječenih stabala 9,2 cm. U 44 forvarderska turnusa ukupno je izvezeno 163 m^3 energentskoga drva, s prosječnim obujmom tovara od 3,7 m^3/turi. Prosječna je udaljenost izvoženja drva iznosila 89 m.

Radne sastavnice sječa te sječa i utovar zastupljene su s 50 % ukupnoga vremena rada (slika 2). Utrošci vremena opterećenoga kretanja vozila zauzimaju 3 %, odnosno neopterećenoga kretanja 4 %, što je posljedica veće udaljenosti između pomoćnoga stovarišta i mjesta prvoga utovara u odnosu na udaljenost između mjesta zadnjega utovara i pomoćnoga stovarišta. Na premještanje vozila tijekom sječe i utovara te istovara drva na pomoćnom stovarištu otpada 6 %, a na manipulaciju 8 % ukupnoga vremena rada. Na kvarove i popravke kraće od 15 minuta otpada 12 %, a na dulje od 15 minuta 11 % ukupnoga vremena rada.

Izraz 1 predstavlja proizvodnost sustava koji obuhvaća sječu i privlačenje drva za energiju. Razlog je korištenju podmodela jediničnih utrošaka vremena (min/m^3) različit broj ciklusa s različitim jedinicama izrade (svežanj stabala, tovar forvardera) koji se javljaju u jednom proizvodnom ciklusu sječe i privlačenja drva opisanim vozilom. Štoviše, opširnije opažanje pojedinih sastavnica rada povećava točnost predviđanja cijeloga modela proizvodnosti.

Tablica 3 prikazuje aritmetičke sredine te 5. i 95. percentile nezavisnih varijabli. Za cijeli model proizvodnosti statistički su značajne samo ove nezavisne varijable: prosječni obujam stabla, udaljenost privlačenja drva te obujam tovara. Nije potvrđena pretpostavka da vrijeme sječe ovisi o faktoru vrste drveća, o nagibu terena, broju stabala u svežnju i sječnoj gustoći kao nezavisnim varijablama. Utrošak je vremena sječe ovisan samo o obujmu stabla (izraz 2). Također samo o obujmu stabla ovisi i utrošak vremena sječe i utovara (izraz 3). Utrošak vremena izvoženja drva ovisi o udaljenosti privlačenja, koja objašnjava 91 % varijabilnosti podataka (izraz 4). Međutim, iako statistički neznačajan, u izraz 4 je uvršten i obujam tovara koji je nužan za izračunavanje jediničnoga utroška vremena (min/m^3).

Utrošci vremena premještanja, utovara, istovara te povremenih radova vrlo su homogeni za svaki pojedini turnus te je utvrđena njihova mala varijabilnost (tablica 4) u odnosu na utroške vremena opisane podmodelima izraz 2, 3 i 4. Stoga su njihovi prosjeci korišteni kao konstantne vrijednosti (tablica 4) u modelu proizvodnosti.

Svi podmodeli jediničnih utrošaka vremena (min/m^3) ne obuhvaćaju prekide rada te su zasnovani na efektivnom satu rada (PSH$_0$). Praksa je da su prekidi rada, kraći od 15 minuta, obično već uključeni u pogonski sat rada (PSH$_{15}$). Poveznicu između proizvodnosti iskazanoj po efektivnom satu, odnosno pogonskom satu rada, predstavlja faktor dodatnoga vremena (k_1), koji je u ovom istraživanju utvrđen u iznosu od 1,15. Tijekom

istraživanja nije bilo kvarova niti se stroj morao održavati, te je u model proizvodnosti uključen faktor dodatnoga vremena u iznosu od 1,3. Pouzdanost modela proizvodnosti istraživanoga vozila za udaljenost izvoženja drva prikazuje slika 3, a za obujam tovara slika 4.

Prosječna ostvarena proizvodnost sječe i privlačenja drva za bioenergane opisanim strojem iznosi 4,11 m^3/PSH_0, odnosno 3,16 m^3/PSH_{15}, s jediničnim troškom od 28,99 EUR/m^3.

Istraživanjem je utvrđeno optimalno područje rada višezahvatne sječne glave Moipu 400E koje iznosi do 30 cm promjera u panju za bor, odnosno do 25 cm za hrast i bukvu. Za djelotvornu primjenu mehaniziranoga pridobivanja drva istraživanim strojem pogodne su sječne jedinice u kojima obujam srednjega sječnoga stabla nadilazi 0,05 m^3.

Osim navedenoga troška dobava drvnoga iverja opterećena je i troškom iveranja te troškom njegova prijevoza. Za pretvorbu kubnoga metra (m^3) u nasipni kubni metar (m_n^3) korišten je pretvorbeni faktor u iznosu od 2,8 (ÖNORM M 7132, 1998). Affenzeller i Stampfer (2007) utvrđuju trošak iveranja u iznosu 8,68 EUR/m^3 (3,1 EUR/m_n^3), a Ganz i dr. (2005) trošak prijevoza iverja u rasponu od 2,3 do 3,3 EUR/m_n^3. Za potrebe ovoga istraživanja trošak prijevoza iverja zasnovan je na vrijednosti od 2,9 EUR/m_n^3 ili 8,12 EUR/m^3 tako da ukupan trošak dobave drvnoga iverja (sječa, privlačenje, iveranje, prijevoz) na energanu doseže 45,79 EUR/m^3 (16,35 EUR/m_n^3). Opći troškovi knjigovodstva i komuniciranja, kao i uredski troškovi te troškovi premještanja, ali i poduzetnička dobit nisu uključeni u kalkulaciju.

Trošak dobave iverja od 45,79 EUR/m^3 odgovara trošku od 77,84 EUR/t (suhe tvari) koji je izračunat korištenjem koeficijenata gustoće suhe tvari bora, hrasta, bukve i ariša (ÖNORM B 3012, 2003) koji su ponderirani s udjelom pojedine vrste u posječenom drvu. Prosječna gustoća suhe tvari iznosila je 587 kg/m^3 (pretvorbeni faktor 1,7). Uz cijenu iverja od 78 EUR/t suhe tvari (Österreichische Forstzeitung, 2008) ukupni se troškovi približavaju granici isplativosti.

S obzirom na to da ukupni trošak dobave iverja ne obuhvaća opće troškove i dobit, šumarski će poduzetnik, da bi ostvario dobit, povisiti cijenu sječe, što povećava troškove pridobivanja drva za energiju te nepovoljno utječe na šumovlasnika. U ekonomskom smislu izračun troškova treba se promatrati kao ulaganje u njegu sastojina s budućnosnim ciljem proizvodnje pilanske oblovine.

Ključne riječi: pridobivanje drva za energiju, proreda, višezahvatna sječna glava Moipu 400E, proizvodnost, troškovi

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