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

Christian Rottensteiner, Günter Affenzeller, Karl Stampfer

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 m³/PSH₀ (effective working hour) or 3.16 m³/PSH₁₅ with an average tree volume of 0.057 m³, an average load volume of 3.71 m³, and the average forwarding distance 89 m.

The supply costs from forest to plant (felling, forwarding, chipping, and transportation) were 91.60 €/PSH₁₅ 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 m³ 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 m³ 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. Delimming and bucking is not necessary to obtain energy wood, therefore simple feller-buncher heads without feed rollers and delimming 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 (Laitila and Asikainen 2006). This study was carried out on either birch or pine dominated stands. When cutting trees of an average of 0.045 m³, the productivity was about 3.5 m³/PSH. In the study by Affenzeller and Stampfer (2007), a productivity of only 1.6 m³/PSH 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
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.

2.5 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:

1. develop a linear model with all co-variables and factors,
2. evaluate non-linearity of co-variables,
3. choose a number of sub-models through removal of non-significant variables,
4. 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 (PSH15) and an expected useful
life of 10,000 PSH₁₅. 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 €/PSH₁₅. 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 land-

ing. 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 m³ were recorded. Total average forwarding distance was 89 m. The average volume of a load was 3.7 solid m³.

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cutting time - $t_{cut}$, min/cycle</td>
<td>Total time for cutting trees, Productive system hour</td>
</tr>
<tr>
<td></td>
<td>Sječa - $t_{cut}$, min/tura</td>
<td>Ukupno vrijeme sječe stabala, pogonski sat rada</td>
</tr>
<tr>
<td></td>
<td>Cutting &amp; Loading time - $t_{cut&amp;load}$, min/cycle</td>
<td>Total time for cutting and loading trees, Productive system hour</td>
</tr>
<tr>
<td></td>
<td>Sječa s utovarom - $t_{cut&amp;load}$, min/tura</td>
<td>Ukupno vrijeme sječe i utovara stabala, pogonski sat rada</td>
</tr>
<tr>
<td></td>
<td>Forwarding time - $t_{for}$, min/cycle</td>
<td>Total time for driving loaded and unloaded, Productive system hour</td>
</tr>
<tr>
<td></td>
<td>Premještanje - $t_{for}$, min/tura</td>
<td>Ukupno vrijeme premještanja između sječe i utovara, pogonski sat rada</td>
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<tr>
<td></td>
<td>Loading time - $t_{unload}$, min/cycle</td>
<td>Total time for loading, Productive system hour</td>
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<tr>
<td></td>
<td>Utovar - $t_{unload}$, min/tura</td>
<td>Ukupno vrijeme utovara, pogonski sat rada</td>
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<tr>
<td></td>
<td>Unloading time - $t_{load}$, min/cycle</td>
<td>Total time for unloading of a load, Productive system hour</td>
</tr>
<tr>
<td></td>
<td>Istovar - $t_{load}$, min/tura</td>
<td>Ukupno vrijeme istovara tereta, pogonski sat rada</td>
</tr>
<tr>
<td>Factor</td>
<td>Tree Species, 2 Levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vrsta drveća, 2 razreda</td>
<td>Scots Pine (0), Oak (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Obični bor (0), hrast (1)</td>
</tr>
<tr>
<td>Covariates</td>
<td>Tree volume - $V_{tree}$, m³ over bark</td>
<td>Average tree volume</td>
</tr>
<tr>
<td>Nezavisne varijable</td>
<td>Obujam stabla - $V_{tree}$, m³ s korom</td>
<td>Prosječni obujam stabla</td>
</tr>
<tr>
<td></td>
<td>No. of trees in a bunch, $n$</td>
<td>Number of trees in a bunch</td>
</tr>
<tr>
<td></td>
<td>Broj stabala u svežnju, $n$</td>
<td>Broj stabala u svežnju (zahvatu)</td>
</tr>
<tr>
<td></td>
<td>Cutting removal, m³ over bark/ha</td>
<td>Timber removal quantity per ha</td>
</tr>
<tr>
<td></td>
<td>Sječna gustoća, m³ (s korom)/ha</td>
<td>Količina posijećenoga drva po ha</td>
</tr>
<tr>
<td></td>
<td>Forwarding distance - $dist$, m</td>
<td>Forwarding distance of a load (average of driving loaded and unloaded)</td>
</tr>
<tr>
<td></td>
<td>Udaljenost izvoženja - $dist$, m</td>
<td>Prosječna udaljenost kretanja neopterećenoga i opterećenoga vozila</td>
</tr>
<tr>
<td></td>
<td>Load volume - load, m³ over bark</td>
<td>Volume of a load</td>
</tr>
<tr>
<td></td>
<td>Obujam tovara - load, m³ s korom</td>
<td>Obujam utovarenoga tereta</td>
</tr>
<tr>
<td></td>
<td>Slope, %</td>
<td>Gradient of slope</td>
</tr>
<tr>
<td></td>
<td>Nagib terena, %</td>
<td>Kut nagiba terena</td>
</tr>
<tr>
<td></td>
<td>Average tree volume of load, m³ over bark</td>
<td>Average tree volume of a load</td>
</tr>
<tr>
<td></td>
<td>Prosječan obujam stabla u tovaru, m³ s korom</td>
<td>Prosječan obujam stabla u tovaru vozila</td>
</tr>
</tbody>
</table>

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

where:

- **PROD**: Productivity of the forwarder equipped with Moipu 400E head, m³/PSH₁₅
- **$k_1$**: Conversion factor from PSH₀ to PSH₁₅
- **$t_{cut}$**: Cutting time, min/m³
- **$t_{load}$**: Loading time, min/m³
- **$t_{cut\&load}$**: Cutting & loading time, min/m³
- **$t_{for}$**: Forwarding time, min/m³
- **$t_{mov}$**: Moving time, min/m³
- **$t_{unload}$**: Unloading time, min/m³
- **$t_{od}$**: Operational delay time, min/m³
- **$V_{cut}$**: Volume that was first cut and then loaded, m³
- **$V_{cut\&load}$**: Volume that was cut and loaded subsequently, m³
- **$V_{tot}$**: Total harvested volume, m³
According 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.

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

Table 3 Means, 5% and 95% Quantile of covariates

<table>
<thead>
<tr>
<th>Covariate Nezavisne varijable</th>
<th>Mean Aritmetička sredina</th>
<th>Quantile5 5. percentil</th>
<th>Quantile95 95. percentil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree volume, m³</td>
<td>0.057</td>
<td>0.012</td>
<td>0.212</td>
</tr>
<tr>
<td>Volume of load, m³</td>
<td>3.71</td>
<td>1.13</td>
<td>5.61</td>
</tr>
<tr>
<td>Forwarding distance, m</td>
<td>88.8</td>
<td>22.0</td>
<td>175.6</td>
</tr>
<tr>
<td>Slope, %</td>
<td>6.9</td>
<td>5.0</td>
<td>10.3</td>
</tr>
<tr>
<td>Number of trees in a bunch, n</td>
<td>2.6</td>
<td>1.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

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.

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

where:
\[
t_{\text{cut}} \quad \text{Cutting time, min/m}^3
\]
\[
V_{\text{tree}} \quad \text{Average tree volume, m}^3
\]

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 m³.

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

where:
\[
t_{\text{cut&load}} \quad \text{Cutting & loading time, min/m}^3
\]
\[
V_{\text{tree}} \quad \text{Average tree volume, m}^3
\]

The time consumption of forwarding (average of driving loaded and unloaded) depends on the forwarding distance (Equation 4). It accounts for 91% of
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 \( \text{min/m}^3 \).

\[
\text{t}_{\text{for}} = \frac{0.028 \cdot \text{dist}}{\text{load}} \quad R^2 = 0.91
\]  

where:
- \( t_{\text{for}} \) — Forwarding time, \( \text{min/m}^3 \)
- \( \text{dist} \) — Average of driving loaded and unloaded, m
- \( \text{load} \) — Volume of a load, \( \text{m}^3 \) (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 (PSH0). In practice down-times of up to 15 minutes are commonly included in the productive machine hours (PSH15) (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 \( \text{m}^3/\text{PSH0} \). Using the factor \( k_1 \) the attained productivity was 3.16 \( \text{m}^3/\text{PSH15} \). This is equivalent to 8.85 cubic metre loose/\( \text{PSH15} \) 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.

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**Table 4.** Means, 5% and 95% Quantile of dependent variables

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Mean</th>
<th>Quantile5</th>
<th>Quantile95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting time – ( t_{\text{cut}} ) ( \text{min/m}^3 )</td>
<td>10.22</td>
<td>2.33</td>
<td>25.99</td>
</tr>
<tr>
<td>Sječa – ( t_{\text{cut}} ) ( \text{min/m}^3 )</td>
<td>13.94</td>
<td>4.59</td>
<td>24.80</td>
</tr>
<tr>
<td>Cutting &amp; Loading time – ( t_{\text{cut&amp;load}} ) ( \text{min/m}^3 )</td>
<td>0.72</td>
<td>0.31</td>
<td>1.67</td>
</tr>
<tr>
<td>Izvoženje drva – ( t_{\text{for}} ) ( \text{min/m}^3 )</td>
<td>1.12*</td>
<td>0.39</td>
<td>1.80</td>
</tr>
<tr>
<td>Moving time – ( t_{\text{mov}} ) ( \text{min/m}^3 )</td>
<td>1.81*</td>
<td>1.00</td>
<td>2.69</td>
</tr>
<tr>
<td>Loading time – ( t_{\text{load}} ) ( \text{min/m}^3 )</td>
<td>1.14*</td>
<td>0.79</td>
<td>1.62</td>
</tr>
<tr>
<td>Unloading time – ( t_{\text{unload}} ) ( \text{min/m}^3 )</td>
<td>1.50*</td>
<td>0.21</td>
<td>3.16</td>
</tr>
<tr>
<td>Operational delay time – ( t_{\text{od}} ) ( \text{min/m}^3 )</td>
<td>0.028 \cdot \text{dist} \times \text{load} \quad R^2 = 0.91</td>
<td></td>
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</tr>
</tbody>
</table>

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

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Fig. 3. Productivity model for the machine system (validity of forwarding distance)

Slika 3. Pouzdanost modela proizvodnosti istraživanoga sustava (udaljenost izvoženja drva)
3.3 Costs – Troškovi

The system costs (net value) of the harvesting system are 91.60 €/PSH15. The fixed costs account for 33.20 €/PSH15, and are at the same level as the operating costs of 33.40 €/PSH15. The labour costs are 25.00 €/PSH15. The average productivity is 3.16 m³/PSH15, and therefore the total costs for felling and forwarding are 28.99 €/m³. 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 €/m³. 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 €/m³. The total costs of felling and forwarding, chipping, and transportation add up to 45.79 €/m³ (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 €/m³ 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/m³, 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 m³/PSH0 or 3.16 m³/PSH15. That is even higher than the productivity for comparable tree volume found by Laitila and Asikainen (2006) who obtained 3.75 m³/PSH15.

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 m³/PSH15 (1.60 m³/PSH0). 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 € per 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 m³, 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 m³/PSH₀ when harvesting trees with an average volume of 0.057 m³ at a forwarding distance of 250 m. This is somewhat better than in this study (4.11 m³/PSH₀). 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 m³.

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 €/m³ 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 m³ whilst the average grapple load size of the felling head used as grapple was just 0.3 m³. 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.

5. References – Literatura


Ocjena višezahvatne sjecne 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 trebaju dodati njega mladih sastojina povećavaju vrijednost vrijednoga drva i smanjuju 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 sjecne glave bez posmičnih valjaka i noževa za kresanje grana. Strojno prorjeđivanje uporabom forvardera s ugrađenom višezahvatnom sjecnom glavom može poboljšati djelotvornost u pretkomercijalnim proredama zbog zahvatanja i sječi više tanjih stabala u jednom radnom hodu dizalice.

Cilj je ovoga istraživanja utjecaj sastojki na proizvodnost i troškove rada osnovnoga forvardera Timberjack 1110D (mase 14,7 t te dopuštena nosivost 12 t) na čiju je dizalicu (umjesto hvatala) ugrađena višezahvatna sjecna glava Moipu 400E pri pridobivanju energentskoga drva (slika 1). Sječna glava siječa, skuplja i zahvaća stabla te tako jedno vozilo siječa, ali i privlači drvo. Sječna glava Moipu 400E teža 540 kg, ima škare za sječu, najveći radni promjer pri sječi pojedinačnih stabala je 30 cm, a 50 cm pri sječi svežnja stabala.


Za istraživanje je odabrana mješovita sastojina običnoga bora i hrasta kitnjaka zbog utvrđivanja utjecaja vrste drva na razinu proizvodnosti i vrijednosti. Strojna sastojina je u dobi između 35 i 40 godina, s dominantnom visinom od 18 m. U drvoj zalihi bijeli bor sudjeluje s 50 %, hrast kitnjak s 40 %, a obična bukva i europski ariš pridolaze u primjeni. Kitnjakova stabla djelomično potječu iz panja, odnosno iz sjemenke. Proredom je gustoća sastojina smanjena s 3500 stabala/ha na 1800 stabala/ha. Sjecačka glava zahvata 170 m2/čl, a prošireni obujam uposjećenog stabala 0,55 m3.

Tijekom rada istraživanje je stroj radio na sljedeći način. Na početku, krećući se unazad, vozilo ulazi u sjecnu, pri čemu se otvara vlak. Stabla na trasi vlake siječa i uhrpava uz njezin rub. Pri povratku iz sječne vozilo tovari posjećenog stabala stabla u svoj utovarni prosor, te završetkom utovara nastavlja se kretati prema pomoćnom
stovarištu, gdje započinje s istovarom. Pri ponovnom vraćanju u sječnu počinje prorjeđivati sastojinu s obje strane, i to s kraja prethodno prosjećene vlake. Pri radu se rabi stabilna metoda izrade drva, tako da se posjećena stabla privlače zajedno s ovršinama i granama. Utovareni svežnji stabala, obujamno (ali ne maseno) nadilaze mogućnosti utovarnog prostora vozila. Tako natovareno vozilo nije se u mogućnosti kretati unazad prema pomoćnom stovarištu, te je stoga prijeko potrebno opisati 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 m², na kojima su prikupljani podaci o terenskim i sastojinskim čimbenicima (nagib terena, sječna gustoća i dr.). Prsni su promjeri stabala mjereni s promjerom, 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 kromometrije i primjenom terenskoga računala Latschbacher EG 20. Radni proces pridobivanja drva za energiju razdijeljen je u radne sastavnice s jasno određenim fiksnačnim 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 prosječne masa stabilnih vozila. Model se proizvodnosti sastoji od sedam podmodela utrošaka vremena, i to: 1) sječa, 2) sječa i utovar, 3) utovar, 4) premještanja, 5) izvođenja, 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 racunalnog programa SPSS 15.0. Analiza svakoga pojedinoga podmodela provedena je po sljedećoj strategiji:

- razvoj linearnoga modela sa svim nezavisnim varijablama i faktorima
- ocjena linearnosti, nezavisnih varijabli
- izbor podmodela izbacićem statistički neznačajnih varijabli
- izbor dvostrukih 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 posjećenih stabala 9,2 cm. U 44 sljedećoj strategiji: provedena uz pomoć računalnog programa SPSS 15.0. Analiza svakoga pojedinoga podmodela provedena je po dvostrukom izboru početne konstante (tablica 4) u modelu proizvodnosti.

Tablica 3 prikazuje aritmetičke sredine te 5. i 95. percentile nezavisnih varijabli. Za cijeli model proizvodnosti podaci o terenskim i sastojinskim čimbenicima (nagib terena, sječna gustoća i dr.) u modelu proizvodnosti.

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Tablica 3 prikazuje aritmetičke sredine te 5. i 95. percentile nezavisnih varijabli. Za cijeli model proizvodnosti

U izboru dvostrukih interakcija podmodela je u modelu proizvodnosti podaci o terenskim i sastojinskim čimbenicima (nagib terena, sječna gustoća i dr.).

Svi podmodeli jediničnih utrošaka vremena (min/m³) ne obuhvaćaju prekide rada te su zasnovani na efektivnom satu rada (PȘH). Praksak je da su prekidi rada, krajci od 15 minuta, obično već uključeni u pogonski sat rada (PȘH). Povećnicu između proizvodnosti iskazanoj po efektivnom satu, odnosno pogonskom satu rada, predstavlja faktor dodatnoga vremena (kt), 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 udaljenosti izvođenja drvja prikazuje slika 3, a za obujam tovara slika 4.

Prosječna ostvarena proizvodnost sjeca i privlačenja droma za bioenergane opisanim strojem iznosi 4,11 m³/PSH0, odnosno 3,16 m³/PSH15, s jediničnim troškom od 28,99 EUR/m³.

Istraživanjem je utvrđeno optimalno područje rada višezahvatne sjecne glave Moipu 400E koje iznosi do 30 cm promjera u panju za bor, odnosno do 25 cm za hраст i bukvu. Za djelotvornu primjenu mehaniziranoga pridobivanja droma istraživanim strojem pogodne su sjecne jedinice u kojima obujam srednjega sjecnoga stabla nadilazi 0,05 m³.

Osim navedenoga troška dobava dromog uverja opterećena je i troškom iveranja te troškom njegova prijevoza. Za pretvorbu kubnoga metra (m³) u nasipni kubni metar (m³n) 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/m³ (3,1 EUR/m³), a Ganz i dr. (2005) trošak prijevoza iverja za energetsku dosežu 2,3 do 3,3 EUR/m³. Za potrebe ovoga istraživanja trošak prijevoza iverja zasnovan je na vrijednosti od 2,9 EUR/m³ ili 8,12 EUR/m³ tako da ukupan trošak dobave dromog uverja (sjeca, privlačenje, iveranje, prijevoz) na energanu doseže 45,79 EUR/m³ (16,35 EUR/m³). Opći troškovi knjigovodstva i komuniciranja, kao i uredski troškovi te troškovi premještanja, ali i pođuzetička dobit nisu uključeni u kalkulaciju.

Trošak dobave iverja od 45,79 EUR/m³ odgovara trošku od 77,84 EUR/t (suhe tvari) koji je izračunan korištenjem koeficijenata gustoće suhe tvari bora, hrasta, bukve i ariša (ÖNORM B 3012, 2003) koji su ponderiran s udjelom pojedine vrste u posjećenom drvu. Prosječna gustoća suhe tvari iznosila je 587 kg/m³ (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 dobiti, povisiti cijenu sjeca, što povećava troškove pridobivanja droma za energiju te nepovoljno utječe na šumoslavljaka. U ekonomskom smislu izračun troškova treba se promatrati kao ulaganje u njegovu sastojina s budućnosnim ciljem proizvodnje pilanske oblovine.

Ključne riječi: pridobivanje droma za energiju, proreda, višezahvatna sjecna glava Moipu 400E, proizvodnost, troškovi

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