Utilization Rates and Cost Factors in Timber Harvesting Based on Long-term Machine Data

Franz Holzleitner, Karl Stampfer, Rien Visser

Abstract – Načrtak

Operating forest machines is not only expensive but accurate monitoring of economic variables can be very difficult. Detailed machine data capture of economic variables within a forest enterprise can be used to support accurate decision making processes, especially costing for new investments.

The objectives of this study were to analyze economic variables of forest machinery based on long-term recorded data from one of the Austrian federal state forest machinery workshops.

The study used data from the enterprise’s resource planning system over the period 2004 to 2008. In total 28 tower yarders, 19 skidders, 12 harvesters and 18 forwarders were analyzed for annual utilization, repair costs, fuel consumption and lubrication costs.

The average annual utilization of all skidders was approximately 1,150 productive machine hours excluding breaks less than 15 minutes (PMH15) per year. Skidders consumed an average 7.3 L/PMH15 with repair costs of 11.4 €/PMH15. For the fully mechanized harvesting system the harvesters achieved 2,040 PMH15/year and the forwarders 2,070 PMH15/year.

The annual utilization of cable yarding systems is between 560 PMH15 and 1,500 PMH15.

Keywords: forest machinery, fuel consumption, machine utilization, repair costs

1. Introduction – Uvod

In 2009 the Austrian annual timber harvest was 16.9 Mio m³. Due to difficult mountainous terrain only 16% were felled and processed with harvesters. Extraction of timber from the stand to forest road side is split with 20% being carried out with cable yarding equipment, 49% with skidders, 26% with forwarders, and 5% with other means (Holzeinschlagsmeldung 2009).

Technical machine limitations, as well as social and environmental compatibility, are main decision criterions that restrict system selection. If multiple systems satisfy these criteria then the most cost-effectiveness will be used. In Austria machine cost calculation for timber harvesting is normally based on the FAO-Scheme, combined and adapted with company related data and conditions (FAO-Forestry Paper 99, 1992).

Machine rate estimation itself depends on the quality of information available for it. Jarack (1965) defined three categories of estimates depending on the sources of data. High quality estimates are calculations based on (1) long-term costs records followed by (2) knowledgeable sources. Estimates with low accuracy (3) are done with not documented or questionable sources or by use of rule-of-thumb values. Therefore high quality data should be used to assure accurate costing. Improved data recording and analyzing is an elementary component of a basic business strategy like in timber harvesting.

One of the most important factors influencing machine cost calculation is the annual use and utilization rate of forest machinery. Annual utilization rate is the ratio of productive to scheduled machine hours. Machine utilization is affected by different factors such as technical reliability of the machines, weather and road conditions, logistics, proportion of set-up time, and the workers. Such information can support strategic and operational decision making processes within a company, especially accurate costing for new investments.
The Austrian Federal Forestry company (ÖBF AG) represents 15% of forest area with a main part under mountainous conditions. It harvests approximately 1.8 Mio m³ per year. Within its organisation it operates two technical divisions that carry out forest operations such as planning, road constructing and timber harvesting. These divisions also offer their services in private forests.

The aim of this paper is to analyse long term machine information from the ÖBF AG to improve data used for cost calculations with a focus on utilization, repair costs, fuel and lubricant consumption. Data set includes harvesters, skidders, forwarders and tower yarders. Additionally factors available for cost calculation of forest machinery are compared with the recorded data.

2. Material and Methods – Materijal i metode

The machine rate is usually divided into ownership costs, operating costs, and labor (FAO-Forestry Paper 99, 1992). Operating costs include maintenance and repair costs, fuel and lubricant costs, tire, track, chain, and cable replacement. Maintenance and repair may include everything from simple maintenance items to the periodic overhaul of engine, transmission, clutch, brakes, and other major equipment components (Bushman et al. 1988).

2.1 Data capturing – Prikupljanje podataka

The study used data from the ÖBF AG resource planning system over the period 2004 to 2008. In total 28 tower yarders, 19 skidders, 12 harvesters and 18 forwarders of different brands and payload capabilities were analyzed for annual utilization, repair costs and fuel consumption. For each machine categorized information was recorded including time elements, fuel quantities and repair and maintenance costs (Table 1).

Both productive and scheduled time was recorded on a daily basis by the crew. Productive time was defined as all machine operating hours including breaks less than 15 minutes in duration (PMH15). Relocation and set-up times are not included in productive machine hours. Scheduled hours include all normal working hours for worker and machine operating in one shift system, but exclude holidays and sick-days and are therefore limited to 1,650 h/year. For all calculations concerning the annual utilization only machines working a full 12 month period were taken into account.

A spreadsheet-based database was developed to combine and prepare the data. Based on these database relevant variables of different forest machineries were filtered and analyzed. For cumulative hours of machines which are older than the period for analyzing the data (i.e. pre-2004) the starting point was taken from the ÖBF AG resource planning system of the machine itself. Regarding the costs for this longer time period, the consumer price index from the Federal Institute of Statistics was taken to refer the costs back to 2004. This is comparable to the method used by Brinker et al. (2002) to compare harvest machine costs in the USA.

3. Results – Rezultati

3.1 Annual utilization – Godišnja iskorištenost

Average annual machine use for harvesters was 2,042 productive machine hours. A maximum annual use of 3,120 PMH15 was recorded when operating multi-shifts in wind-throw in Sweden. The majority of their operations are carried out in Austria, but during this time they also contracted abroad due to a big wind-throw event in Scandinavia. The aver-

Table 1 Overview of machines and models observed during data capturing

<table>
<thead>
<tr>
<th>Attributes - Obilježja</th>
<th>Machine types - Vrste strojeva</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvester</td>
</tr>
<tr>
<td>Number of studied machines, n</td>
<td>12</td>
</tr>
<tr>
<td>Number of models, n</td>
<td>4</td>
</tr>
<tr>
<td>Range of engine power, kW</td>
<td>125-204</td>
</tr>
<tr>
<td>Range of cumulative operating time 2004 to 2008, PMH15</td>
<td>143-12,937</td>
</tr>
</tbody>
</table>
The scheduled machine hours in Austria for a harvester in single shift is 1,650 PMH\textsubscript{15}. Within this machine group different harvester types show a considerably higher annual machine use than the average. The reason is that the Austrian Federal Forestry company uses a special work shift model. This system uses two workers and results in the machines being used seven days a week. Using this work shift model the scheduled machine hours are 3,300. The average machine utilization rate for all harvesters was 62\% (Table 2).

Forwarders have the largest average productive hours per year with 2,068 PMH\textsubscript{15} among the investigated machines. They work the same shift model as harvesters. Variability in the hours is greater than that of harvesters, as forwarders are also used after motor-manual felling. Forwarders have the same annual scheduled machine hours as harvesters, being 3,300 hours. This results in a slightly higher machine utilization rate of 63\%.

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The results also show for skidder use a clear seasonal effect with higher use in winter time. Because of this effect productive machine hours ranged from 355 to 1,619, and averaged 1,151 PMH\textsubscript{15} per year. The annual scheduled machine hours for a skidder are 1,650 hours. This results in a machine utilization rate of 70\%.

Tower yarders show the average productive hours of 1,083 PMH\textsubscript{15}/year. The difference in annual use is clearly visible. The annual scheduled machine hours for a tower yarder are 1,650 hours. This results in a machine utilization rate of 66\%. A double shift system for cable yarding in steep terrain is not possible as light conditions limit the choker.setter and the faller.

### 3.2 Repair costs – Troškovi popravaka

Average repair cost for harvesters were 20.2 €/PMH\textsubscript{15} based on the consumer price index benchmarked back to 2004. Forwarder and skidders had almost the same cost per hour with 11.2 € and 11.4 €, respectively. Tower yarders are the highest with 28.0 €/PMH\textsubscript{15} (Table 3). No correlation was found between the amount of repair cost and annual utilization or the summarized utilization per year.

### 3.3 Fuel consumption and lubricants

**Potrošnja goriva i maziva**

Fuel consumption of harvesters ranged from 10.2 to 24.3 L/PMH\textsubscript{15} with an average of 15.6 L/PMH\textsubscript{15}. The calculations yielded the average fuel consumption for forwarders of 11.1 L/PMH\textsubscript{15}. Skidders show the lowest consumption rate with 7.3 L/PMH\textsubscript{15}. They also have lighter engines as shown in Table 1. Tower yarders consume 16.0 L/PMH\textsubscript{15}. In combination with fuel prices, the fuel cost per hour including cost for lubricants were also analyzed (Table 4).

When analyzing fuel consumption according to engine power, tower yarders show the lowest fuel consumption with 0.06 L per hour and kilowatt, followed by skidders with 0.08 L/kW, PMH\textsubscript{15}. Forwarders and harvesters are close together with 0.10 and 0.09 L/kW, PMH\textsubscript{15} (Table 5).
Further analysis estimated the rate of fuel consumption per hour depending on the engine power and type of forest machine. The significant covariates are the machine type (MT) and power of engines used by different machines. In the next step a model based on the data was developed (Table 6 and Table 7). The model (1) shows an adequate R-Square with 63%.

Table 4 Descriptive statistics concerning fuel consumption and lubricant costs

<table>
<thead>
<tr>
<th>Machine type</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>St. Dev.</th>
<th>5 Perc.</th>
<th>95 Perc.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvester – Harvester</td>
<td>15.6</td>
<td>10.2</td>
<td>24.3</td>
<td>3.3</td>
<td>11.3</td>
<td>23.0</td>
<td>36</td>
</tr>
<tr>
<td>Forwarder – Forwarder</td>
<td>11.1</td>
<td>1.3</td>
<td>20.5</td>
<td>3.1</td>
<td>7.4</td>
<td>17.4</td>
<td>55</td>
</tr>
<tr>
<td>Skidder – Skidder</td>
<td>7.3</td>
<td>3.6</td>
<td>11.3</td>
<td>2.1</td>
<td>4.0</td>
<td>10.8</td>
<td>77</td>
</tr>
<tr>
<td>Tower Yarde – Stepna zicara</td>
<td>16.0</td>
<td>3.3</td>
<td>24.8</td>
<td>4.2</td>
<td>8.9</td>
<td>23.2</td>
<td>91</td>
</tr>
</tbody>
</table>

Table 5 Descriptive statistics concerning fuel consumption per hour dependent on the engine power, L/kW, PMH₁₅

<table>
<thead>
<tr>
<th>Machine type</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>St. Dev.</th>
<th>5 Perc.</th>
<th>95 Perc.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvester – Harvester</td>
<td>0.095</td>
<td>0.077</td>
<td>0.119</td>
<td>0.012</td>
<td>0.077</td>
<td>0.118</td>
<td>36</td>
</tr>
<tr>
<td>Forwarder – Forwarder</td>
<td>0.098</td>
<td>0.011</td>
<td>0.146</td>
<td>0.020</td>
<td>0.077</td>
<td>0.129</td>
<td>55</td>
</tr>
<tr>
<td>Skidder – Skidder</td>
<td>0.075</td>
<td>0.031</td>
<td>0.117</td>
<td>0.020</td>
<td>0.041</td>
<td>0.108</td>
<td>77</td>
</tr>
<tr>
<td>Tower Yarde – Stepna zicara</td>
<td>0.060</td>
<td>0.023</td>
<td>0.108</td>
<td>0.017</td>
<td>0.034</td>
<td>0.089</td>
<td>91</td>
</tr>
</tbody>
</table>

Table 6 Analysis of variances concerning the variables

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Square</th>
<th>df</th>
<th>Mean of Square Varianca</th>
<th>F</th>
<th>Sig. Značajnost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Model – Prilagođeni model</td>
<td>4,046,514</td>
<td>4</td>
<td>1,011.628</td>
<td>108.289</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Constant – Konstanta</td>
<td>358,487</td>
<td>1</td>
<td>358,487</td>
<td>38.374</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Engine power – Snaga motora</td>
<td>448,686</td>
<td>1</td>
<td>448,686</td>
<td>48.029</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Machine type – Vista stroja</td>
<td>871,332</td>
<td>3</td>
<td>290,444</td>
<td>31.090</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sum – Zbroj</td>
<td>45,725,424</td>
<td>259</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted Sum of Variation Prilagođena suma varijabilnosti</td>
<td>6,419,360</td>
<td>258</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum – Zbroj</td>
<td>6,134,037</td>
<td>255</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
With the previous analysis the following model was developed:

$$f_c = 5.055 + \text{power}^{0.04} + CMT$$  \hspace{1cm} (1)

Where:

- $f_c$ fuel consumption, L/PMH
- $P$ engine power, kW
- $CMT$ coefficient machine type:
  - Tower yarder – $CMT = 0$
  - Harvester – $CMT = 3.924$
  - Forwarder – $CMT = 1.488$
  - Skidder – $CMT = -1.744$

Based on the developed model, fuel consumption can be estimated for different forest machine types. Fig. 1 shows observed data and estimates. Estimating fuel consumption per hour was just done based on the machine data available.

### 4. Discussion – Rasprava

Information regarding machine utilization and repair costs gives forest engineers a useful tool for cost-evaluation in logging operations. This study used long term machine data captured by the ÖBF AG for 4 different machine categories, and each category included multiple machines for a total of 77 machines. The data used were from the period 2004 – 2008.

The average annual use is reported for all machines. The data show that the average utilization rates ranged from a low of 62% for the harvesters up to a high of 70% for skidders. The new working shift model, used by the Austrian Federal Forestry Company for their harvesters and forwarders, shows a clear increase in the annual machine use in comparison to the skidder and tower yarder. According to

![Figure 1](image-url)
Spinelli et al. (2011), the average annual utilization of harvesters and forwarders with 1,439 and 1,617 hours per year reaches 70% and 78%, respectively, of the value in this study. Spinelli and Visser (2008), based on a large number of separate time studies, determined an average delay for harvesters of 28.9%. Therefore, the utilization rates from that study are almost the same. Repair costs showed a high variability between machine types and with the cumulative operating time.

In Finland the repair and maintenance costs for harvester and forwarder averaged 9.66 €/h and 5.06 €/h, respectively. The fuel consumption for harvesters and forwarders were about 12.79 L/h and 10.76 L/h. Repair and service costs (classified as variable costs) of a logging contractor with a harvester-forwarder in Finland was studied by Väätäinen et al. (2006) and covered 6.2% of total costs. Maintenance costs defined as fixed costs accounted for 5.3% of total costs.

Pausch (2002) reported fuel consumption of 14.1 L/h for a medium sized harvester compared to 15.4 L/h for the model developed in this study. Löffler (1991) estimates the average fuel consumption for a forwarder with a medium sized engine of approximately 9.7 L/h compared to 10.9 L/h in this study.

The model for estimating fuel consumption could be improved with further investigation using more detailed data capture. It must also be mentioned that for life cycle analysis, fuel consumption of machinery has to be calculated differently. Self-driven tower yarders already included the fuel necessary for relocating the machinery. Skidders, harvesters and forwarders just show the figures concerning the logging processes without any relocating processes.

Currently data is being recorded manually by the ÖBF AG and their crews. In future data availability and calculation of results could be automated with defined interfaces between costing and enterprise resource planning system. Cost calculation could, therefore, be based on online data from the ERP for new machinery or for harvesting costs. Further work could also include more detailed data capture for investigating parameters influencing the repair costs of forest machines. The results of this paper can also be applied as basic information in life cycle assessment.

Acknowledgements – Zəhwəla

The authors would like to thank Erwin Stampfer from the Austrian Federal Forest Agency for providing the data and useful information for this paper. They also want to thank Mohammad Reza Ghaffariyan for the data preparation.

6. References – Lıteratura


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Sažetak

Iskorištenost i troškovni faktori strojeva pridobivanja drva temeljem dugoročnoga preračuna

Među najvažnije čimbenike koji utječu na izračun troškova strojnih rada jest godišnja uporaba i stopa iskorištenosti šumskih strojeva. Godišnja je stopa iskorištenosti stroja omjer proizvodnoga (pogonskoga) i ukupnoga radnoga vremena. Iskorištenost je stroja pod utjecajem različitih čimbenika, kao što su: tehnička ispravnost strojeva, vremenski uvjeti, stanje cesta, logistika, priprema rada (npr. montaža i demontaža žičnih linija), radnici. Takve informacije mogu pomoći u postupku donošenja strateških i operativnih odluka u tvrtki, a osobito u točnom utvrđivanju troškova prilikom novih investicija.

Austrijske savezne šume (ÖBF AG) gospodare s 15 % površine austrijskih šuma, čiji je glavni dio u planinskih područjima te siječe oko 1,8 mil. m³ godišnje. Poduzeće je organizirano u dva odjela koji provode šumske zahvate: planiranje radova, izgradnju cesta i pridobivanje drva. Ti odjeli izvode radove i u privatnim šumama.

Cilj je ovoga rada analizirati dugoročne podatke o strojevima dobivene od ÖBF-a radi unapređenja korištenja podataka za izračun troškova s naglaskom na godišnju iskorištenost strojeva, troškove popravaka te potrošnju goriva i maziva. Podaci obuhvaćaju harvestere, skidere, forvardere i stupne žičare. Dadać podaci o šumskim strojevima dostupni za izračun troškova uspoređeni su s ranijim objavama.


Proizvodno i ukupno radno vrijeme na dnevnoj osnovi snimali su radnici. Proizvodno (pogonsko) vrijeme određeno je kao svi radni sati stroja, uključujući i prekide rada kraće od 15 minuta (pogonski sati rada). Premještanje strojeva i vrijeme pripreme rada (kod žičara montaža i demontaža) nisu uključeni u proizvodno vrijeme. Ukupno radno vrijeme uključuje sve normalne sate rada strojeva u jednoj smjeni, ali isključuje praznike i bolovanja te je stoga ograničeno na 1650 sati godišnje. Za sve izračune povezane s godišnjom iskorištenošću uzeti su u obzir samo strojevi koji su radili svih 12 mjeseci u godini.

Baze podataka koje služe za pripremu i obradu podataka razvijene su u tabličnom kalkulatoru. Temeljem tih baza podataka odabrane su i analizirane odgovarajuće varijable različitih šumskih strojeva. Za cjelokupne (kumulativne) sate rada strojeva koji su stariji od razdoblja za koje su analizirani podaci (tj. prije 2004), početna je točka preuzeta iz ÖBF-ova sustava planiranja resursa za pojedin stroj. Za isto razdoblje podaci su o troškovima definirani pomoću indeksa potrošačkih cijena dobivenih od Saveznoga zavoda za statistiku.


Među analiziranim strojevima forvarderi imaju najviši prosječno ostvarenost od 2068 pogonskih sati rada, pri čemu rade u Austriji, ali tijekom promatranog razdoblja ugovoreni su i radovi u inozemstvu zbog velike količine vjetroizvora u Švedskoj. Prosječan fond radnih sati forvardera u Austriji za jednu smjenu iznosi 1650 pogonskih sati rada. Tijekom smjenskoga rada za četvrtak satu rade, a rezultat je da strojevi rade sedam dana u tjednu. Primjenom toga modela smjenskoga rada određen je fond radnih sati iznosi 3300 sati. Prosječna je stopa iskorištenosti forvardera 62 %.

Među analiziranim strojevima skidere stori se najniža godišnja uporaba od 688 pogonskih sati rada, pri čemu rade u Austriji, ali tijekom promatranog razdoblja ugovoreni su i radovi u inozemstvu zbog velike količine vjetroizvora u Švedskoj. Prosječan fond radnih sati skidera u Austriji za jednu smjenu iznosi 1650 pogonskih sati rada. Tijekom smjenskoga rada za četvrtak satu rade, a rezultat je da strojevi rade sedam dana u tjednu. Primjenom toga modela smjenskoga rada određen je fond radnih sati iznosi 3300 sati. Prosječna je stopa iskorištenosti skidera 62 %.

Rezultati, također, pokazuju jasan sezonski utjecaj pri uporabi skidera s većim iskorištenošću u sezone razdoblju. Zbog toga je utjecaj pogonski sati rada kreću se u rasponu od 355 do 1619, a u prosjeku iznose 1151 pogonski sati rada. Fond radnih sati skidera iznosi 1650 sati godišnje. Fond radnih sati skidera iznosi 1650 sati godišnje, što rezultira iskorištenošću od 1151 pogonskih sati rada. Tijekom smjenskoga rada za četvrtak satu rade, a rezultat je da strojevi rade sedam dana u tjednu. Primjenom toga modela smjenskoga rada određen je fond radnih sati iznosi 3300 sati. Prosječna je stopa iskorištenosti forvardera 62 %.
Sustav dvostrukih smjena za iznošenje drva žičarom na nagnutom terenu nije moguć zbog ograničenja trajanja dnevne svjetle za kopčaša i sjekača.


Prosječna potrošnja goriva harvestera iznosi 15,6 L, a forvardera 11,1 L po pogonskom satu rada. Skideri pokazuju najnižu prosječnu potrošnju goriva od 7,3 L (u odnosu na druge strojeve imaju i najlažše motore, tablica 7), a stupne žičare najvišu od 16,0 L po pogonskom satu rada. U kombinaciji s cijenom goriva analizirani su i troškovi goriva po satu, uključujući i troškove maziva.

Trenutačno radnici ÖBF-a snimaju podatke ručno. Dostupnost podataka i izračun rezultata u budućnosti mogu biti automatizirani, s definiranim sučeljima između sustava planiranja resursa i troškova unutar poduzeća. Izračun troškova može biti temeljen na online podacima ERP-a za nove strojeve ili za troškove pridobivanja drva. Daljnji rad može također uključiti prikupljanje preciznijih podataka za utvrđivanje parametara koji utječu na troškove popravaka šumskih strojeva. Rezultati ovoga rada mogu se također primijeniti kao temeljna informacija u postupku utvrđivanja analize životnoga ciklusa šumskih strojeva.

Ključne riječi: šumski strojevi, potrošnja goriva, iskorištenost stroja, troškovi popravaka

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Received (Primljeno): August 6, 2011
Accepted (Prikvaćeno): September 5, 2011