# Productivity of Chainsaw Felling and Processing in Selective Forests of Croatia

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**Abstract:**
*In Croatia, one-worker chainsaws were introduced in the early sixties. Felling and processing has been partly mechanized and since then trees are felled and processed into timber assortments motor-manually. Fully mechanized harvesting is used mainly just in forest cultures and plantations, but in all natural forests, including the selective ones, chainsaw is still a major means of work for felling and processing.*
*The majority of selective forests in Croatia grows in the region of Lika and Gorski Kotar. Precisely the region of Gorski Kotar is the most afforested part of our country. Some 75% of its surface is covered with forests, so the inhabitants of Gorski Kotar are traditionally and inseparably linked to the forest and forestry.*
*The study was conducted in selective felling site to determine the productivity of workers in the motor-manual felling and processing of timber assortments. Snap-back chronometry method was used for recording time consumptions of individual work elements (walking to the tree, felling, processing, scaling) and delays. Net volume of produced timber assortments was measured for all investigated trees. A regression analysis of dependence of individual work elements time consumptions on the trees DBH was conducted and a productivity model based on an eight-hour work-time was constructed.*
*During the seven days of research (1944.72 min), 1109.75 min (57.06%) of effective time and 834.97 min (42.94%) of delay time was recorded. Analysis of delays provided the allowance time as 61.21% of effective time. In the structure of delay time the forefront was the delay due to rain, but the same, given the climatic characteristics of the study area, was recognized within allowance time. A very strong correlation between the DBH and time consumption for felling of trees and for processing of timber assortments was found.*
*The projected daily output of felling and processing ranged from 9.65 $m^3$ for trees of DBH class 17.5 cm to 45.89 $m^3$ for trees of DBH class 72.5 cm. Based on a calculative direct daily cost of felling and processing the unit cost was determined. It ranged from HRK 13.42/$m^3$ (€ 1.81/$m^3$) for trees of DBH class 72.5 to HRK 63.83/$m^3$ (€ 8.59/$m^3$) for trees of DBH class 17.5 cm.*

**Keywords:** selective forest, motor-manual felling and processing, productivity, cost

## 1 Introduction

The majority of selective forests in Croatia grow in the region of Lika and Gorski Kotar. Precisely the region of Gorski Kotar is the most afforested part of our country. Some 75% of its surface is covered with forests, so the inhabitants of Gorski Kotar are traditionally and inseparably linked to the forest and forestry.

Since the introduction of one-worker chainsaws and partial mechanization of felling and processing to date trees are felled and processed into timber assortments motor-manually. Fully mechanized harvesting is used mainly just in forest cultures and plantations, but in all natural forests, including the selective ones, chainsaw is still a major means of work for felling and processing.

For decades, in the forests of Gorski Kotar felling and processing was performed by hand tools (axes and hand saws), and timber extraction was done by animal power. Chainsaws were introduced in the period of 1958 to 1960 (Merle 1984). In the beginning they were used only for felling and all other tasks were done

by hand tools. The traditional processing methods were maintained. Timber assortments were produced at the stump and debarked by hand. After the drying period, produced wood assortments were gathered by animal hauling at the sky-lines or the forest rail-lines. In the following years the forests are gradually opened by the forest roads and skid trails. The use of adapted farm tractors for timber skidding began, and trucks were more and more used for distance transport. However, until the early seventies and the introduction of skidders for timber extraction (Krpan 2000) no significant change in the organization of felling and processing occurred. Only the use of more powerful and purpose-built cable skidders enabled the extraction of freshly produced timber assortments of larger dimensions. Debarking of produced timber in the forest is gradually omitted, which significantly increases the productivity of felling and processing. The use of tree-length and half-length harvesting method resulted with the higher productivity of timber skidding. Part of the processing operation was transferred from the stand to the landing and roundwood was produced in lengths suitable to means of distance transportation (Sabo & Poršinsky 2005). In recent time, due to the sensitivity of selective forest stands to damage of standing trees and regeneration, maximum load piece length in limited. Therefore, in felling and processing, along with the cut-to-length (assortment) method, shorter timber assortments combined into optimal lengths are produced without final cross-cutting in the forest, as a compromise between the organizational, economic and environmental demands on present timber harvesting.

**Research goal**

The aim of this research was to determine the productivity of motor-manual felling and processing of fir and spruce trees in selective stand, to construct a mathematical model with the DBH as an input and to calculate the unit cost.

## 2 Material and methods

The study was conducted in the management unit "Lazac" (45º22'- 45º34' N, 14º32 '- 14º37' E), the state forest managed by the "Croatian Forests" Ltd., Forest Administration Delnice, Forest Office Gerovo. In the area of management unit, which borders with the national park "Risnjak", fir forests, beech-fir forests and sub-mountain beech forests grow. The nearest meteorological station "Parg" (45°36' N, 14°38' E) is located at 863 m above sea level.

The study was conducted in sub-compartment 25 A, selective forest stand (*Omphalodo-Fagetum* Marinček et al. 1992) of an area of 25.25 ha at an altitude of 930 m to 1060 m and slope from 1° to 20°. Before harvesting, there were 558 trees per hectare and the growing stock was 543 $m^3$/ha. Silver fir (*Abies alba* Mill.) with the 40.56% and Norway spruce (*Picea abies* (L.) H. Karst.) with the 39.56% prevailed in the growing stock, followed by common beech (*Fagus sylvatica* L.) with 18.86% and other hard broadleaves with 1.03%.

From the total of 998 trees (2448.85 $m^3$) marked for felling 618 trees (1961.73 $m^3$) were fir and spruce trees. The sample included 54 fir and spruce trees, which was 8.7% of the total number of the marked fir and spruce trees. Average DBH of marked trees and sample trees was in the DBH class 52.5 cm.

Cut-to-length felling and processing was performed by a professional forest worker, employed in state company, with 50 years of age and 23 years of cutter work experience. He was using a Stihl MS 440 chainsaw (power of 4.0 kW, mass of 6.3 kg and 45 cm guide bar length).

Cutter's work was investigated by time and motion study (Zečić et al. 2004) during seven work days in the spring of 2010. Time consumptions of individual work elements, as well as the delay times, were recorded using snap-back chronometry method. In the research work elements were precisely divided by fixed points. In this way time consumptions for walking to the tree, felling (determining the felling direction, workspace clearing, face cut, back cut, tree falling), processing (delimbing, cross-cutting, stump debarking & slash piling) and assortments scaling were recorded. The analysis of recorded delays provided allowance time ($f_{all}$) (Zečić 1999). For all sample trees diameter at breast height was measured. Recorded effective times and measured net volume of assortments (technical roundwood and pulpwood),

determined in accordance with the Croatian Standards for Products of Forest Utilization (1995), were allocated to each sample tree.

Based on the research results, regression analysis of net volume of assortments ($v_{net}$), of time consumption for felling ($t_F$) and of time consumption for processing ($t_P$) versus diameter at breast height (*DBH*) were performed. For walking to the tree ($t_W$) and scaling of produced timber assortments ($t_S$) average time consumption per tree was used in the further calculations. A mathematical model (1) for calculating eight-hour shift daily output ($P_{8h}$) was constructed, with a diameter at breast height ($d_{1.30}$) as the only input parameter.

$$(1)\quad P_{8h} = \frac{480}{f_{all} \times (t_W + t_F + t_P + t_S)} \times v_{net} \quad \left[\frac{m^3}{day}\right]$$

Unit cost was determined based on a calculative direct daily cost of felling and processing (HRK 616.00) in "Croatian Forests" Ltd. for 2011. Monetary values were converted into Euros according to the average annual exchange rate of Croatian National Bank for 2011 (€ 1.00 = HRK 7.43).

## 3 Results

During the seven days of research a total of 142.95 $m^3$ net volume of wood assortments was produced for which 1944.72 min was consumed. Of that the effective time (Table 1) accounted for 1109.75 min (57.06%), and delay time (Table 2) for 834.97 min (42.94%). Disproportion between the time available over seven working days (3360 min) and recorded time (57.88%) originated as a consequence of bad weather conditions; the rain which in some days permanently prevented the work after only four hours.

**Table 1: Effective time structure**

| Work element | Time consumption [min] | [%] |
|---|---|---|
| Walking | 27.35 | 2.46 |
| Felling | 155.25 | 13.99 |
| Processing | 804.33 | 72.48 |
| Scaling | 122.82 | 11.07 |

**Table 2: Delay time structure**

| Delay element | Time consumption [min] | [%] |
|---|---|---|
| Preparatory | 76.97 | 9.22 |
| Meal | 260.22 | 31.16 |
| Rest | 34.45 | 4.13 |
| Technical | 112.27 | 13.45 |
| Other unavoidable | 334.00 | 40.00 |
| Avoidable | 17.07 | 2.04 |

Preparatory time, rest time, technical delays and other unavoidable delays were in total amount recognized as allowance time, while the meal time was recognized as 6.25% of the total recorded time. The allowance time factor 1.61 was established. Even 21.64% of the allowance time was consumed by rainfall interruptions (in the other unavoidable delays). Namely, according to the statistical data (1971 -

2000) of the Meteorological and Hydrological Service for meteorological station "Parg" precipitation in the Gorski Kotar are abundant (1840.9 mm/year) and frequent (153.4±37.8 mm/month) with a minimum in February (113.5 mm/month) and a maximum in October (230.9 mm/month). Therefore, although the work is usually terminated in the case of the rain, brief showers, which are a common phenomenon in the research area, are tolerated depending on the assessment of prospects for work continuing. Obviously a relatively small share of registered rest delay is a consequence of rainfall interruptions at which rest time was actually realized.

In the structure of the net volume of produced timber assortments (N = 252) technical roundwood (N = 166) accounted for 83.71% (119.66 $m^3$) and pulpwood (N = 86) for 16.29% (23.29 $m^3$). Descriptive statistics of the volume, the mean diameter under bark and the length of assortments are shown in Table 3.

**Table 3: Descriptive statistics of produced timber assortments**

| N = 252 | Diameter [cm] | Length [m] | Volume [$m^3$] |
|---|---|---|---|
| Average | 34 | 5.9 | 0.57 |
| Minimum | 9 | 1 | 0.03 |
| Maximum | 62 | 10.9 | 1.63 |
| Standard deviation | 13.91 | 2.03 | 0.37 |

Based on the data on net volume of produced timber assortments by tree, regression analysis was performed and a quadratic equation, which explains 88.18% of variability, was used for net volume to DBH dependence (Figure 1).

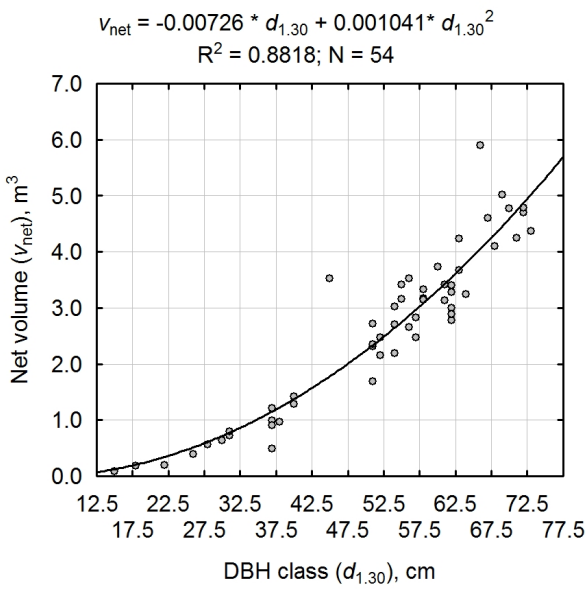


**Figure 1: Net volume vs. DBH**

Exponential equations were used for regressing the time consumption of felling (Figure 2) and the time consumption of processing (Figure32) versus DBH. These equations explain 78.23% and 78.73% of variability, respectively. The difference in the number of sample trees is a consequence of the fact that three of the sample trees were blown down by the wind and time consumption for the felling of one tree was recognized as an extreme value.

As the work on scaling the produced timber assortments was done periodically with the cutter assisting the forestry technician in measuring and marking of assortments, in a mathematical model for calculating the daily output (1) average time consumption per tree in the amount of 2.27 min was used. For the walking to the tree the average consumption per tree in the amount of 0.51 min was used in the same model.

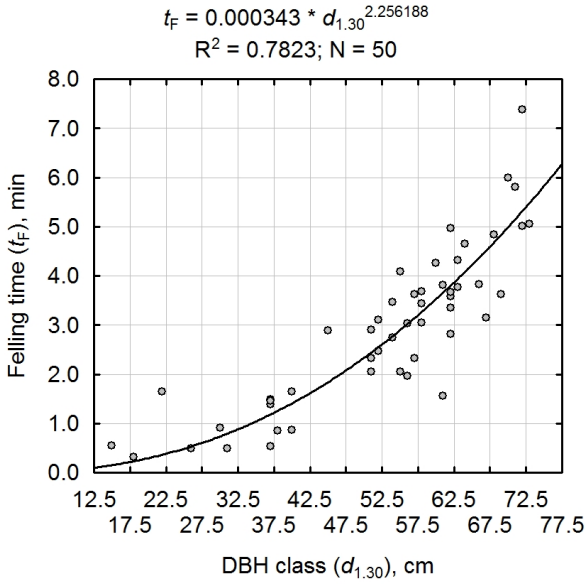


**Figure 2: Felling time vs. DBH**

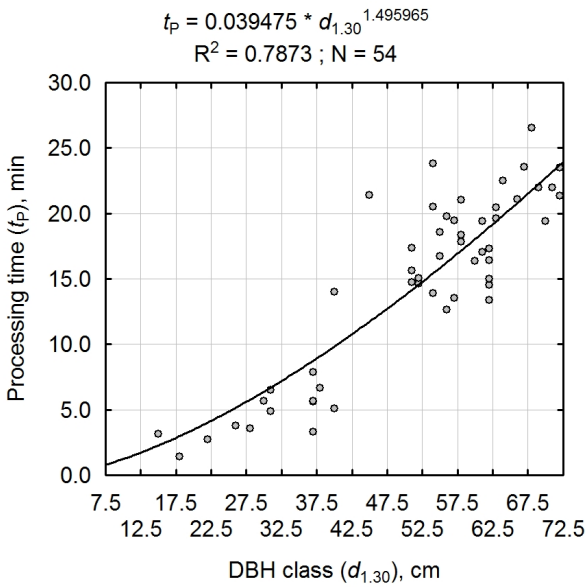


**Figure 3: Processing time vs. DBH**

By inserting the corresponding regression equations and the average time consumptions in the general form of the mathematical model for calculating the daily output (1) a mathematical model to calculate the productivity of felling and processing, under conditions of the investigated felling site, is constructed.

Daily output (Figure 4) increases from 9.65 $m^3$/day for the DBH class 17.5 cm to 45.89 $m^3$/day for the DBH class 72.5 cm, and the unit cost (Figure 4) for the same DBH classes decreases from HRK 63.83/$m^3$

(€ 8.59/m$^3$) to HRK 13.42/m$^3$ (€ 1.81/m$^3$). For specific conditions of the felling site (DBH class 52.5 cm) daily output is 36.75 m$^3$, and unit cost amounts to HRK 16.76/m$^3$ (€ 2.26/m$^3$).

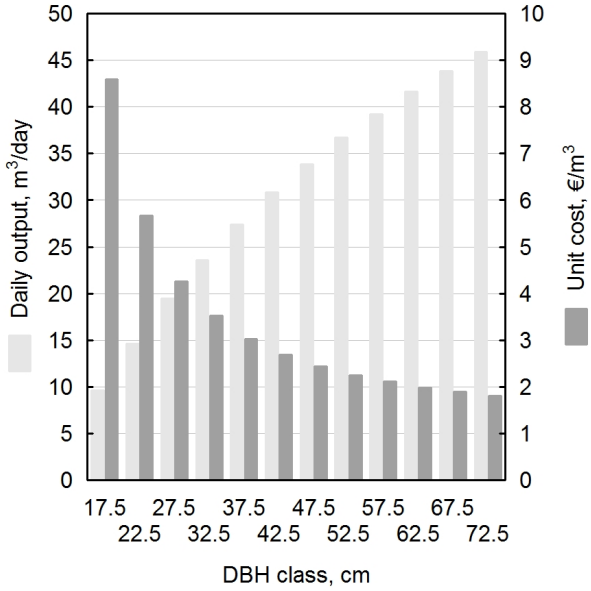


**Figure 4: Daily output and Unit cost vs. DBH class**

## 4 Discussion

Since the time of the introduction of chainsaws, productivity of the felling and processing in the selective forests of Gorski Kotar increased because of modifications of harvesting method, changes in work organization and technological improvement of chain saws. Bojanin in 1974 stated that in summer felling and processing of hand debarked technical fir roundwood by cut-to-length method debarking amounted to 44% of the effective time of felling and processing. The standard time (without the slash piling operation) in mentioned study ranged from 26.86 min/m$^3$ for trees of DBH 75 cm to 68.07 min/m$^3$ the for trees of DBH 35 cm. In the period from 1982 to 1987 extensive field research (2600 man-days recorded) of felling and processing work in selective forest of Croatia was conducted (Martinić 1990) in order to design the system of differentiated technical standards. This research also resulted in publishing of scientific publications. Martinić (1988) compared the productivity of felling fir trees and processing them into long technical roundwood and pulpwood under conditions with and without snow, and Vondra (1989) presented the results on the influence of harvesting methods and ecological management forest type on the productivity of felling and processing firwood. Martinić (1988) found no statistically significant difference between the time consumptions of felling and processing in snow-free conditions (standard time amounts from 12.16 min/tree for trees of DBH class 17.5 cm to 62.77 min/tree for trees of DBH class 72.5 cm) and conditions with an average snow depth of 25 cm (standard time amounts from 9.67 min/tree for trees of DBH class 17.5 cm to 67.56 min/tree for trees of DBH class 72.5 cm). Vondra (1989) for a harvesting method identical to here researched determined the effective time consumption of 6.20 min/tree for tress of DBH class 17.5 cm to 36.80 min/tree for trees of DBH class 72.5 cm in phytocenosis *Abieti-Fagetum illyricum* Ht., and from 4.87 min/tree for trees of DBH class 17.5 cm to 48.82 min/tree for trees of DBH class 72.5 cm in phytocenosis *Blechno-Abietetum picetosum* Ht.

For trees of DBH class 52.5 cm, compared with the results of Martinić (1988), for conditions without snow, the standard time determined in this study is about 25% lower, and compared with the results of Vondra (1989) the effective time consumption determined in this study is about 18% lower than in phytocenosis *Abieti-Fagetum illyricum* Ht. and about 30% lower than in phytocenosis *Blechno-Abietetum picetosum* Ht.

When interpreting the results of this research one should bear in mind that in average only 57.88% of available daily working hours were utilized. This could have influenced the productivity increase due to the smaller cumulative fatigue and longer daily rest after work. Besides that, the reasons for the differences in the productivity of felling and processing in selective forests determined in this study and previous research (Martinić 1988, Vondra 1989) can be explained by technological improvements in chain saws in the last thirty years, the diversity of stand and exploitation conditions that obviously occur in selective forests, and by the fact that the results of the research conducted in the period from 1982 to 1987, given the sample, can be in the true sense of the word considered as an average productivity, while the results of this study should be considered as an information about the achievable productivity in observed conditions and as an indication of a trend of increasing productivity in motor-manual felling and processing in selective forests.

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