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COMPARISON OF MECHANIZED AND MOTOR-MANUAL CUTTING OPERATION IN MIXED STANDS OF SOUTHERN SLOVENIA

USPOREDBA MEHANIZIRANE I RUČNO-STROJNE SJEČE U MJEŠOVITIM SASTOJINAMA JUŽNE SLOVENIJE

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Summary

By increasing the diversity of conditions influencing the forest operation we are often faced with the dilemma of combining Motor manual and Cut to length technologies. The results of time study and productivity of cutting and skidding operation in mixed stands with a substantial proportion of deciduous trees are presented. Older pole stand was divided into four homogeneous strata in which forest operation was executed by applying two different technologies (motor manual and cut to length), each on two research areas. The objective of this study was to identify the influential factors which could be used as guidelines in the decision support system evaluating the suitability of both technologies. The results show that the mechanized cutting productivity is statistically significantly different for different tree morphological characteristics. In order to set up general guidelines it was established that the productivity in stands with single-trunked, short crown and thin branches processed with Cut-to-length technology is 25% higher than in the comparable stands consisting of multi-trunked trees, deep crowns with thick branches in terms of diameter at breast height structure.

KEY WORDS: cut-to-length, motor-manual, hardwood, time study, working techniques, productivity.

INTRODUCTION
UVOD

Traditional long-wood systems, based on motor-manual cutting and wood extraction with tractors and cable cranes diminish (hereinafter referred to as MM) and are gradually replaced with the Cut-to-length technology (hereinafter referred to as CTL).

In most cases the CTL technology is applied by using harvester and forwarder in forest operation. Given the natural conditions and stand characteristics in Slovenia we had to face the challenge of adapting the mechanized cutting forest operation to a large diversity of terrain, stand and forest ownership which affects the competitiveness of CTL technology compared to traditionally used MM technology. Forest operation is carried out in diverse topography, intensive variety of stand conditions on a relatively small area, relatively large tree dimensions and approximately the same share of growing stock between conifers and deciduous trees. Large trees also open question of combining MM and

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CTL technology (Forst-Platte-Papier, Institut fur Alpine Naturgefahren und Forstliche Ingenieurwesen, 1991). Density of forest skid roads is mainly adapted to prevailing tractor skidding, but regarding sufficient for CTL technology. In addition, there is also the ownership structure which is dominated by very small private forest properties (Medved et al. 2008, Pezdevšek Malovrh et al. 2010).

Background – *Prethodna istraživanja*

Despite the huge diversity of working conditions, CTL technology is in an expansion and consequently in many places effectively competes with currently dominant MM technology. We are facing a period when the new and old technologies are used close to each other – sometimes in nearby and similar working conditions. The advantages of both technologies within the various stages of production processes vary. Economic advantages of each technology are not the only reason for its choice. The process of modernization is therefore affected by many aspects of forest operation (safety, disposal of technical and human resources, human capacity building and tradition in conducting the forest operation, storm damaged forest), which have an important role in the implementation and dynamics of technological modernization.

The need for the introduction and use of CTL technologies is also expressed through trends, volume and structure of allowable cuttings. Total felling volume recorded in Slovenia in 2012, according to the Slovenian Forest Service (SFS, 2012), was 3,910,807 m^3 with 2,152,467 m^3 of conifers and 1,758,348 m^3 deciduous trees. The average tree volume which has been cut in the last 14 years at the state level was 0.75 m^3 (SE 0.09 m^3) and was lower in broad-leaved trees 0.59 m^3 (SE 0.04 m^3) than in conifers 0.94 m^3 (SE 0.15 m^3). The SFS report indicates that the amount of allowable cuttings is increasing in the last period.

The recorded cuttingis significantly lower than the maximum allowed annual cut (SFS, 2012). SFS recorded the largest deficit in the realization of cutting in private forests, even though analysis including the data from permanent sample plots shows a different picture (Medved et al. 2008). There are several reasons of unrealized cuttings in private forests. The cost exceeds revenues, particularly in younger stands. The forest owner alone is independent in that respect and often very selectively, i.e. from tree to tree, decides what will be cut and what kind of technology will be used. The use of CTL technology makes speculation of the rising amount of early thinning more certain. Solving the problem of economically proven early thinning of conifer and mixed stands will therefore have an important influence on future market opportunities – not only in this country but in other countries of Central Europe as well.

Modern cutting technology has been developed in northern countries basically for conifers stands. Cutting broadleaves with CTL technology in those countries has always had small importance. The productivity of mechanized cutting together with cost evaluation in those stand and terrain conditions was often the research subject – mainly in the Scandinavian countries (Lageson 1997, Eliasson 1998, Glöde 1999, Kärhä etal. 2004, Ovaskainen 2005, Nurminen et al. 2006). Having in mind the prevailing work condition in Scandinavia it is understandable that researchers have primarily examined the impact factors like tree species, dimensions and the cutting pattern and intensity on productivity of CTL technology. These approaches have been also followed in Central European countries with some peculiarities concerning terrain slope (Hittenbeck 2013, Visser and Berkett 2015) and thinning intensity (Stampfer 2001). Many authors have focused on original studies or compilation of different studies from abroad relating to CTL operation under different terrain conditions or machines but ignored the problem of cutting different tree species (i.e.: Bültemeier et al. 1998, Neruda, Valenta, 2003).

The impact of broadleaved tree species and associated morphological characteristics of trees on the mechanized cutting productivity has been studied less.Thus, it was established in Sweden that the productivity of the mechanized cutting was the most affected by the average size of trees and number of cutting trees per hectare (Lageson 1997). They also recorded greater productivity in the final felling in comparison to the selective cutting (thinning operation).

Productivity depends on stand density and tree species, too. We have anticipated that the main reasons for different productivity in broadleaved stands are tree species morphological characteristics and wood hardness. Some authors do not distinguish working times between softwood and hardwood species in places where hardwoods are not dominant and do not exceed volume more than 0.4 m^3 / tree (Pausch, 2002). There is more interest paid in studies of CTL techniques in broadleaves in southern countries where mixed stands are more frequent (Poršinsky, Krpan, 2004). In situation like this the demand for developing different models which can evaluate the impact of unmeasured combinations on calculated productivity and cost calculations are frequent and are not discussed here.

We assume that mechanized cutting in hardwood stands compared with those of conifer stands is more pretentious, the productivity is lower and the proportion of productive time is smaller compared to the work in conifer stands. The advantages of modern technologies are therefore less obvious and are shown only on the specific sites, working fields and stand conditions. The main influential factors on the productivity of mechanized cutting of hardwood stands are tree species, their dimension, cutting intensity, size and shape of crowns, thickness of branches and morphology of stem form. Tree and terrain characteristics also affect the quality of bucking in both CTL as well as cutting and processing with chainsaw (Han, Renzia 2005).

Similar to our research was conducted by Serbian researchers dealing with efficiency of mechanized cutting in Poplar plantations (Danilović et all, 2011). The main aim was to study productivity when different methods of work are used and tree forking effect on the time needed for steam processing. They found considerably longer (52%) average time needed to process forked steams in Poplar plantations.

In coniferous stands (black pine) the impact of tree's forkness on work productivity using mechanized cutting was analyzed in Croatia (Vusić and Rukavina, 2010). They elaborated productivity models for time consumption for straight and forked tress, which show considerable decrees in productivity (between 50% and 70%) for forked trees.

The assessment of the effectiveness has also been included in the study of suitability of their use (Krč, Košir 2003). In particular, the study discussed the economics of CTL introduction (Krč 2004) and the effectiveness of machine operators' training for work with harvester and forwarder (Malovrh etal. 2004).

In the year 2010, the research focusing on standard times for large harvesters (John Deere 1270D, John Deere 1470D, Ecolog 580C) has been concluded by Slovenian Forest Institute for the purposes of national standard times tables. Standard times are valid for most frequent use of harvesters (together with forwarding) in thinnings of conifers and broadleaves (cutting intensity between 50 and 100 m^3/ha). Following the Slovenian tradition, the trees were marked as were also the trails for cutting and forwarding. The average tree in a cutting unit did not exceed 1.8 m^3 for conifers and 1.5 m^3 for broadleaves (maximum cutting diameters 60 cm, tip-to-tip diameters up to 40 cm). Combinations between chain saw and harvesters have been recorded, but not included in the final report. One of the main problems has been recording and evaluation of delay times. The technology has not been stabilised yet and several different work day organisations have been met.

Purpose of the research – *Cilj istraživanja*

Current professional work study and research efforts are mainly concerned with the mechanized cutting in association with wood forwarding.

This study focuses on young hardwood stands and has the following objectives:

1. Identification of differences in the productivity in cut-to-length technology (mechanized cutting) for typical values of the influential variables,
2. Comparison of productivity between fully mechanized cutting and motor-manual cutting, skidding with tractors of different kind.
3. Analyzing the structure of unproductive time. It is assumed that the reduced productivity in hardwood stands compared with the conifers stands largely reflects in higher share of unproductive time. Consequently, there is a smaller proportion of the main productive time due to difficult working conditions, and in particular the hardness of wood and unfavorable morphology in comparison with conifers stands.

MATERIALS AND METHODS
MATERIJALI I METODE

Experimental sites – *Područje istraživanja*

The research area is located in the southeast region of Slovenia, in the vicinity of the town Novo Mesto, regional forest management unit Mirna Gora. The prevailing plant association (*Omphalodo – Fagetum galietosum odorata)* is one of the best in the Dinaric fir-beech forest sites, now secondary forest of silver fir, spruce and beech with a capacity up to 8.9 m^3/ha of annual increment. The section is located on moderate slopes with its altitude ranging between 810 and 930 m. Relief is undulated and sink-holed, mostly of north-east orientation with a maximum slope of 45 %. Rockiness is due to dolomite bedrock very small, but the ground bearing capacity is not problematic and considered above average in the wider region.

The experimental plots (Figure 1, strata I to IV), belong to the developmental stage of older pole-wood stand (DBH between 20 and 30 cm). The current stand tree structure on experimental plot consists of beech dominated stands (13.86 ha) with Norway spruce and maple (*Acer sp.*). On a small part of the section (4,6 ha) there are Norway spruce pole stands with mixture of deciduous trees while the rest includes pole-wood stand of beech (*Fagus sylvatica*) with a mixture of mountain maple (*Acer pseudoplatanus*).There are also portions of low quality mature spruce stand with a mixture of deciduous trees in the sink-holes, with deep soil and rich in nutrients. In some parts of the studied area there are separated trees of mountain elm (*Ulmus glabra*). Table 1 shows the volume structure of stand by extended DBH size classes.

The average growing stock is 338 m^3/ha. The total ten-year allowable cut defined by forest management plan for forest compartment (basic forest inventory unit) amounts to 861 m^3 for conifers and 1,841 m^3 for deciduous trees, and together represents 22.1% of the total growing stock. Most of the stand originates from the time after 1918 when there was a forest rail-way causing clear cuttings along its track. The new stand developed from a mixture of artificially introduced spruce and natural regeneration of fir and various deciduous species from the wider surroundings. The stands were never thinned with the exception of some remnants

Table 1: Shares of wood volume by tree species and extended DBH classes in study stand

Tablica 1: Udjeli drvne zalihe u pokusnim plohama prema vrsti drveta i razredima prsnih promjera

Tree Species *Vrsta drveta*	The share of wood volume [%] *Udio drvne zalihe*	Extended DBH class *Proširene klase promjera*		
		Less than 30 cm [%] *Manje od 30 cm [%]*	30–50 cm [%]	Over 50 cm [%] *Više od 30 cm [%]*
Spruce /*Smreka*	31.8	52.0	42.4	5.6
Fir/*Jela*	0.8	47.5	37.4	15.2
Beech/*Bukva*	54.2	65.4	27.8	6.7
Oak/*Hrast*	0.2	70.0	26.7	3.3
Maple/*Javor*	10.4	65.7	27.7	6.6
Elm/*Brijest*	0.9	66.1	29.4	4.6
Cherry/*Trešnja*	1.6	65.8	28.6	5.6
Sum/*Ukupno*	100.0	61.1	32.5	6.4

of older stands. On the predominated part of the research stands the second commercial thinning was carried out.

The research area openness with cutting and skidding paths for timber harvesting has been adapted to CTL technology. One part of tractor and forwarder skid-roads was built in advance in those places where harvesters were not able to work. In the selected strata of experimental plots for motor-manul method (chainsaw cutting, skidding with a tractor) there was 2,265 m of new marked tractor skidding trails on the area of 16.46 ha. The openness with skidding trails for motor-manual cutting and tractor skidding was 209 m/ha. On two randomly chosen plots for CTL technology there were 5,969 meters of skid trails marked in total. Together with the prior existing infrastructure (roads and skidding trails) there was an average openness of 450 m/ha (Figure 1).

Experiment Design – *Plan istraživanja*

The studied stand was divided into two experimental treatments, each with two repetitions, where randomly CTL (I and III) and / or MM (II and IV) technology with tractor skidding was used (Figure 1).

Within the stratums, clearly visible numbers were painted on marked trees in advance. For each number (each tree separately), the following characteristics were recorded:

- Tree species,
- Breast-height diameter,
- Stem form (single, forked trees – double trunked trees, multi-trunked trees form),
- Length of the crown (½ tree height, 1/3 tree height, ¼ tree height),
- Average thickness of branches (up to 10cm, between 10 and 15cm, above 15cm),
- Additionally, some specifics of tree (for instance highly bending trunks) were recorded.

The average values of harvested trees by species and DBH dimensions are shown in Table 2.

Altogether, there were 229 trees cut by applying CTL technology with the total volume of 83.33 m^3, an average DBH of 19.55 cm and average tree volume of 0.36 m^3. Volume structure by tree species for mechanized cutting is shown in Table 3. The cutting intensity (ratio between removed and initial stand volume) was 25.3 % on two CTL cutting

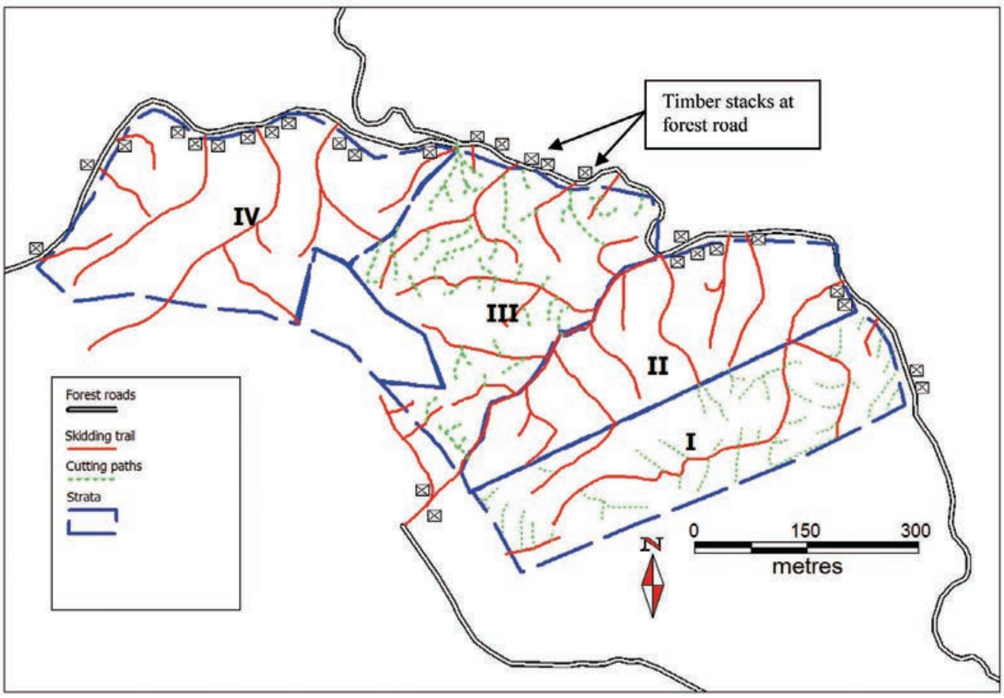

Figure 1 Study area map divided into experimental treatments with forestry infrastructure

Slika 1. Područje istraživanja podijeljeno na pokusne plohe sa šumskim prometnicama

Table 2. Tree species and DBH structure of felled trees for both CTL and motor manual technology

Tablica 2. Vrsta drveta i promjeri oborenih stabala za mehaniziranu i ručno-strojnu sječu

Technology	CTL / mehanizirana sječa			MM / ručno-strojna sječa		
Tree species *Vrsta drveća*	No. *Broj*	Average DBH [cm] *Prosječni DBH [cm]*	Std. Dev. [cm] *Standardna devijacija [cm]*	No. *Broj*	Average DBH [cm] *Prosječni DBH [cm]*	Std. Dev. [cm] *Standardna devijacija [cm]*
Beech/ *Bukva*	185	18.49	6.38	157	15.99	4.52
Maple/ *Javor*	39	23.03	5.89	54	16.65	4.88
Spruce/*Smreka*	5	31.80	12.11	13	28.08	8.83
Total/*Ukupno*	229	19.55	6.89	224	16.85	5.66

stratums and 23.3 % on two stratums where MM cutting and tractor skidding operation was applied.

The time study was made according to IUFRO recommendations using handheld computer) as shown on Table 4. The analysis of CTL technology included two days of recorded data or 13.3 hours of work place time. Productive machine time includes work related delays up to 15 min. The time study of MM cutting and tractor skidding was made in four days, recording 24.74 hours of total work place time. All technologies were divided into standard work elements with separation of Work and Non-work time (Table 4).

In order to determine the productivity of cutting and processing operation, we made the inventory of cut trees. Felling was carried with harvester machine Timberjack 1270 D with

Table 3 Structure of the felled trees on two CTL treatments (I and III)

Tablica 3. Struktura posječenih stabala u dva tretmana mehanizirane sječe (I i III)

	Total *Ukupno*	Beech *Bukva*	Maple *Javor*	Spruce *Smreka*
No. of trees / *Broj stabala*	229	185	39	5
Volume / *Volumen* [m^3]	83.33	57.57	19.78	5.97
Mean volume / *Prosječni obujam* [m^3]	0.36	0.31	0.51	1.19
Std. deviation / *Standardna devijacija* [m^3]	0.33	0.28	0.31	0.71

harvesting head H 754, built for softwoods. The range of hydraulic boom was 11.5 m. The harvester was used to prepare log piles on the skidding trails; timber extraction was carried out by forwarder Timberjack 1010 D.

All statistical analyses were carried out in the statistical package SAS. Data of productive time was analyzed on the logarithmic scale to reduce heteroscedasticity.

RESULTS
REZULTATI

The impact of morphological characteristics of trees on the productivity of CTL – *Utjecaj morfoloških parametara stabala na učinak harvestera*

In order to compare productivity between MM and CTL technologies we performed time study of work element cutting and processing in dependence to recorded tree mor-

Table 4. Work time elements classification for CTL and MM cutting technology

Tablica 4. Klasifikacija radnog vremena za mehaniziranu i ručno-strojnu sječu

Technology (*skidding machine*) *Tehnologija rada (stroj za privlačenje)*	Time *Vrijeme*	Work elements classification *Klasifikacija radnih sastavnica*
CTL (Forwarder)	Work time / *Radno vrijeme*	Moving to the site, Driving on the site, Driving in the stand, Positioning of the machine, Positioning-to-cut, Felling and processing, Clearing, piling residues *Vožnja do radilišta, Vožnja po sječini, Pozicioniranje harvestera, Pozicioniranje glave harvestera, Sječa i izrada, Čišćenje okoliša, Uhrpavanje šumskog ostatka*
	Non- Work time/ *Neradno vrijeme*	Service Time, Planning Time, Rest and Personal Time, Meal time, Disturbance Time *Vrijeme servisiranja, Vrijeme za izradu operativnih planova rada, Vrijeme za odmor i osobne potrebe, Pauza za ručak, Vrijeme prekida*
MM (Tractor)	Work time *Radno vrijeme*	Preparing for felling, Felling cut, Undercut, Wedge driving at felling, Release the caught tree, Root collar processing, Bucking and crosscutting, Limbing, Clearing the site with the chainsaw, Clearing the site manually, Searching and moving to the next marked tree *Priprema na rušenje, izrada zasjeka, potpiljivanje, zabijanje klina, oslobađanje zaustavljenih stabala, obrada perca, prikrajanje i trupljenje, kresanje grana, čišćenje okoliša motornom pilom, čišćenje okoliša–ručno, traženje i premiještanje do sljedećeg stabla.*
	Non- Work time/ *Neradno vreme*	Workers short rest time and other delays because of workers needs Maintenance Time, Refueling Time, Repair Time, Planning Time, organization delays, Meal Time, Operational preparatory time *Kratki odmori i prekidi zbog osobnih potreba, održavanje, dopunjavanje goriva, popravak, planiranje, ogranizacijski prekidi, Pauza za ručak, pripremno-završno vrijeme*

Table 5. Average daily workplace time for mechanized cutting (CTL)
Tablica 5. Prosječno radno vrijeme u danu kod harvestera

WORKING ELEMENT / *Radni element*	[%]	[min]
Driving on the site/ *Vožnja do radilišta**	2	9.6
Driving in the stand/ *Vožnja po sječini**	12	57.6
Positioning of the machine / *Pozicioniranje harvestera**	1.5	7.2
Positioning-of harvester head / *Pozicioniranje glave harvestera* *	6.7	32.2
Felling and processing (Main Work Time) *Sječa i izrada (Glavno radno vreme)*	40.7	195.4
Productive time total / *Produktivno vrijeme–zajedno*	62.9	302
Rest and personal time / *Kratki odmori i prekidi zbog osobnih potreba* *	6.1	29.3
Service Time / *Održavanje* *	4.2	20.2
Work Related Delay Time / *Ogranizacijski prekidi* *	9.8	47.0
Disturbance Time (time study. visitors) / *Smetnje (snimanje, posjete)**	3.7	17.8
Change-Over Time / *Pripremno-završno vrijeme* *	4.2	20.2
Meal time / *Vrijeme za objed* *	9.1	43.7
Non-Work Time / *Neradno vrijeme**	37.1	178

(*not included in impact analysis of characteristics tree/stand factors) / (*nije uključeno u analizu utjecajnih čimbenika stabala/ sastojine*)

phological characteristics. Additionally, by using the productivity data we compared the efficiency of both technologies, separated by the general stand characteristics determined by morphological characters of the trees.

In the mechanized cutting operation we recorded the share of 62.9 % of productive time, out of which the Main work time (Felling and processing) was 64.7 % while the rest pertained to Complementary work time 35.3 % (Driving in the stand /site, Positioning of the machine, Positioning of the harvester head). The structure of Work Place time with respect to Work time and Non-work time is within limits for similar operations elsewhere.

The impact of individual factors which are related to tree characteristics was studied by the analysis of the Main Work time (Felling and processing). The analysis of felling and processing time has included the following independent variables: DBH, crown length, branch thickness and stem form. The distribution of cut trees by influential factor classes is shown in Table 6.

By regression analysis we determined which of the influential factors has a statistically significant impact on felling and processing. The results showed that the linear regression model is significant for explanation of efficiency in Main Work Time. The model explains 76 % variance (R^2 = 0.76), but the contributions of individual variables are very different (Table 7).

The variables with a statistically significant impact are the breast height diameter (DBH) and stem form. We conducted the analysis of covariance where the dependent variable was felling and processing time. We used DBH as covariate; the stem form was used as an independent variable which also has statistically significant influence on productivity.

Furthermore, we tested the level of interaction between independent variable (stem form) and covariate (DBH).

The analysis of the characteristics of the interaction between covariate (DBH) and independent variable (stem form) shows the atypical interaction of both variables. Even partial Eta squared is close to zero and this may further confirm the assumption that there is a small proportion of variation explained by the interaction of both variables. Therefore, we can accept the assumption that the covariate variable (DBH) is homogeneously distributed within the value of independent variable (steam form).

In Table 8 the average values of Main productive time by stem form classes for CTL technology are shown.

The expectation of increasing average main productive time consumption by the classes of stem forms are confirmed – that is by a growing class of tree forking. The statistical tests were conducted in order to qualify the conditions of the performance in the covariance analysis (Table 9).

The analysis of covariance shows that the stem form has a statistically significant impact on work element Felling and

Table 6 Frequency distribution of the removed trees by morphological characteristics for CTL
Tablica 6. Distribucija morfoloških značajki harvesterom posječenih stabala

Tree Characteristics / *Morfološka karakteristika stabala*	Class / *Razred*	Number of trees / *Broj stabala* n = 229
Crown class / *Razred krošnje*	1/2 tree height / *½ visina stabala*	10
	1/3 of tree height/ *1/3 visina stabala*	42
	1/4 tree height/ *½ visina stabala*	177
Stem form class / *Razred oblika stabala*	Single/ *Jedno deblo*	179
	Double trunked trees/ *Dva debla*	42
	Multi-trunked / *Više debala*	8
Average thickness of branches/ *Prosječna debljina grana*	Up to 5cm / *Do 5 cm*	100
	5–10 cm	69
	Over 10 cm / *Više od 10 cm*	60

Table 7 Linear regression model of logarithmic transformation for Main Work Time by set of analyzed influential factors
Tablica 7. Model linearne regresije logaritamski transformiranih podataka za glavno produktivno vrijeme sa analiziranim utjecajnim faktorima

Model / *Model*	B	Std. Dev / *Standardna devijacija*	Beta	t	
(Constant/ *Konstanta*)	0.688	0.102		6.734	0.000
Crown class/ *Razred krošnje*	0.028	0.026	0.043	1.073	0.285
Stem form/ *Razred oblika stabala*	0.093	0.025	0.139	3.721	0.000
Branch thickness/ *Debljina grana*	0.040	0.022	0.096	1.853	0.065
DBH	0.037	0.003	0.754	14.627	0.000

Table 8 Mean values of Main productive time by stem form classes
Tablica 8. Prosječne vrijednosti glavnog produktivnoga vremena po razredima oblika stabala

Stem form *Oblik stabala*	Mean [min] *Prosječno*	Std. Dev. *Stanadardna devijacija*	N *Broj*
Single / *Jedan*	0.85	0.66	179
Double / *Dva debla*	1.64	1.20	42
Multi-trunked / *Više debala*	4.05	1.22	8
Total / *Ukupno*	1.11	1.03	229

Table 9 Analysis of covariance testing productivity between the classes of stem form (covariate DBH)
Tablica 9. Analiza kovarjiance u testu produktivnosti između razreda oblika stabala (kovarijanca DBH)

Source *Izvor*	Type III Sum of Squares *Vrsta III Suma kvadrata*	df	Mean Square *Srednji kvadrat*	F	Sig.	Partial Eta *Djelimičan Eta*
Corrected Model *Ispravljen model*	20.255[a]	3	6.752	240.439	0.000	0.762
Intercept *Intecepcija*	11.660	1	11.660	415.237	0.000	0.649
DBH	13.782	1	13.782	490.794	0.000	0.686
Stem form *Oblik stabala*	0.469	2	0.235	8.355	0.000	0.069
Error *Pogreška*	6.318	225	0.028			
Total (n of cases) *Ukupno (broj slučaja)*	675.444	229				
Corrected Total *Ukupno (ispravljeno)*	26.573	228				

a. $R^2 = 0,762$ (Adjusted $R^2 = 0,759$) / $R^2 = 0,762$ (*Prilagođen* $R^2 = 0,759$)

processing (when harvester head is in direct contact with tree) excluding the DBH as covariate effect.

In order to test productivity on the basis of tree characteristics we made separated comparisons inside feasible unique thickness of the trees from 15 to 20 cm DBH (both types of tree characteristics were available), classifying the trees into two classes:

a. single-trunked, short crown and thin branches,

b. multi-trunked, long crown, thick branches.

The results showed that by the average tree 0.21 m^3 (DBH 17,5 cm) in stands of privilege class (a class) for mechanized cutting has a 25 % higher productivity than in stands where there are multi-trunked trees with deep crown (b class). Consequently, we conclude that the felling and processing costs of mechanized felling and processing are 25 % lower in younger stands with average DBH 17,5 cm.

In order to test the same influence of tree morphological characteristics on productivity we executed the time study for MM cutting and tractor skidding. The analysis according to the morphological tree characteristics showed minor differences in productivity. When processing tall trees (class a) with the average volume of 0.21 m^3 the average productivity was 2.77 m^3/hour. It amounted 16 % more than productivity of multi-trunked trees with long crown (class b).

Efficiency analysis – *Analiza učinkovitosti*

For the purpose of comparing the efficiency of both technologies, we conducted the analysis of the Main work time. The reason of using Main work time as a dependant variable was an objective to find a direct impact of the tree size on the efficiency (Table 10). In case of mechanized cutting we analyzed all the working elements where the harvesting head was in direct contact with a tree (it includes following working elements: felling, delimbing, bucking and crosscutting). In MM cutting we also took into consideration all working elements that were directly related to the processing of tree (felling cut, undercut, wedge driving at felling, root collar pro-

Table 10 Dependence of efficiency in main work time on DBH by technology
Tablica 10. Zavisnost učinkovitosti produktivnog radnog vremena od promjera stabla i tehnologije

DBH [cm] *Promjer*	CTL / mehanizirana sječa				MM / ručno-strojno sječa			
	Main work time [min/tree] *Produktivno radno vrijeme*	SE [min/ tree] *Standardnadevijacija*	Produ-ctivity [min/m^3] *Produktivnost*	No. of Trees *Broj stabala*	Main work time [min/ tree] *Produktivno radno vrijeme*	SE [min/ tree] *Standardnadevijacija*	Produ-ctivity [min/m^3] *Produktivnost*	No. of Trees *Broj stabala*
5–9	0.27	0.1	32.62	16	0.98	0.96	51.58	10
10–14	0.45	0.18	6.03	41	1.46	0.5	20.86	79
15–19	0.68	0.32	3.29	66	2.09	1.06	9.92	71
20–24	1.07	0.48	2.71	50	3.07	1.41	7.49	38
25–	2.36	1.3	2.83	56	6.08	2.56	8.94	5

Table 11: The share of felled trees where delays were recorded and stem form structure for both CTL and MM technology
Tablica 11: Udio oborenih stabala sa snimkom kašnjenja i struktura oblika stabala za mehaniziranu i ručno-strojnu sječu

DBH class / Stem form class *Debljinski razred / oblika stabala*	Delay *Kašnjenje* CTL	Steam form structure *Struktura oblika stabala* CTL	Delay *Kašnjenje* MM	Stem form structure *Struktura oblika stabala* MM
I (<30 cm)	6,50	100,00	28,08	100,00
Single / *Jedan*	6,54	86,99	27,54	94,52
Multi-trunked / *Više dabala*	6,25	13,01	37,50	5,48
II (30–50 cm)	2,70	100,00	47,22	100,00
Single / *Jedan*	2,04	66,22	53,57	77,78
Multi-trunked / *Više dabala*	4,00	33,78	25,00	22,22
III (>50 cm)	28,57	100,00	50,00	100,00
Single / *Jedan*	33,33	42,86	100,00	50,00
Multi-trunked / *Više dabala*	25,00	57,14		50,00
Total / *Ukupno*	6,64		32,07	

cessing, bucking and crosscutting, delimbing). The comparison results are shown in Table 10.

The difference between largest and smallest DBH is more than three times and generally decreases by increasing the tree DBH size. Observing the Main work time we noticed that the variability in productivity is generally increasing with increasing tree dimensions by CTL and decreases by MM technology. Results are partly influenced by number of samples, which is for larger DBH classes very small.

Delays – *Prekidi rada*

The share of unproductive time has a large impact on the efficiency of both CTL and motor manual technology. We separated delays (worker, machine and organization related – for instance organization delays, disturbance time) from the entire non-work time. The distribution of recorded trees regarding delays is shown in table 11.

Table 11 shows large average differences in recorded delays between the two analyzed technologies (6,64 versus 32,07 percent). In both cases recorded delays increase with DBH class. The ratio between CTL and MM shares decreases with increasing DBH class. Consequently, we assume that this is an important reason that the comparative advantage of CTL technology decreases in the same direction (with increasing DBH class). We cannot confirm that delays are more likely to occur in single vs. multi-trunked trees for either CTL or MM technology.

DISCUSSION AND CONCLUSIONS
RASPRAVA I ZAKLJUČCI

We have expected higher differences in productivity observing only Main work time between the analyzed technologies in favor of mechanized cutting. Past research reported the average ratio of 1:7 in favor of mechanized cutting in conifers stands. The results show that in observing the average mechanized Main work time (direct contact with a tree), CTL is only 3 times more efficient than theMM cutting.

The ratio between MM and CTL productivity is higher in the coniferous stands, which is logical; delimbing represents a significantly larger proportion of the working time by MM cutting in young coniferous stands than in hardwood stands. Glöde (1999) reported that harvester Valmet 892/960 had delimbing problems in pine stands with the average branches diameter more than 7 cm and in birch stands with branches more than 8 cm in diameter at a place of cutting off (delimbing). He concluded that most delays occurred in working element processing the tree.

We analyzed the reasons for spending additional time for cutting and processing of multi-trunk trees. In the case of forked trees the operator had many problems with tree processing. The following situation was very often recorded: the tree crown begins immediately after the twig, which is an additional obstacle because the processor head does not develop a sufficiently high velocity for a successful delimbing. In the situation of multi-trunked trees difficulties are even greater. Operator must drop the tree to the ground by every point /occasion/ where tree forks and after that rehold it, consequently prolonging the delimbing time. The feeding rollers and cutting knives of harvester head do not develop sufficient force for the successful cutting off branches.

In comparison the MM cutting of multi–trunked tress does not cause as many problems; additional delimbing has to be done which in terms of working technique and productivity does not differ from the single-trunked processing. The most time-consuming work element is therefore delimbing. It can be concluded that the mechanized cutting has higher suitability in the stands dominated by single-trunked trees with thin branches and short crown.

Morphological characteristics of trees also affect the productivity of mechanized cutting. We calculated the productivity of 7.36 m^3 per PMH in the single-trunked stands. The average tree volume was 0.21 m^3. This productivity was 25 % higher than in the stands with multi-trunked trees with a long crown.

The ratio between Work place time and Work time was 1: 1.62. This ratio is higher than ratios (1.39), which has been used for calculation of recommended standard times of CTL cutting with heavy harvesters on the Slovenian state level or the one recorded in Austria (1.35) (Stampfer, 2001). Spinelli and Visser (2008) also report lower coefficients. Explanation of this difference was not a specific subject of this study. However, the problem can be pointed out relating to work organization and delays which are connected with it (repairs, refueling, workers breaks, meal time etc.).

The time study of mechanized cutting and processing shows that the Main work time (when harvester head is in direct contact with the trunk), amounts to 63.4% of work time. In comparison to studies in the coniferous stands (Nurminen et al. 2006), it is closer to those at work in the final fellings, where the authors report 62 % share of Main work time (felling and processing) in the final felling and only 45 % main work time share in the mechanized thinning operation.

The presented findings are the results of study where the productivity was compared for both technologies (MM cutting vs. CTL technology in deciduous stands). Certainly we know that a comprehensive assessment which would analyze additional influential factors (the cutting intensity, environmental impact, ergonomic load, different technological solutions) – would be much more complex. Such a complex study would give different and more general relationships for suitability of forest operation technologies in hardwood stands.

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Sažetak

Povećanjem raznolikosti uvjeta koji utječu na šumske operacije, često smo suočeni s nesuglasicama između tradicionalnih i modernih tehnologija. U radu su prikazani rezultati studije vremena rada i proizvodnosti sječe i privlačenja drva u mješovitim sastojinama sa značajnim udjelom listača. Starija sastojina podijeljena je na četiri jednaka dijela u kojima su izvedene šumarske operacije primjenom dviju različitih tehnologija (ručno-strojna i strojna sječa i izradba), svaka od njih na dvije površine.

Cilj istraživanja bila je usporedba proizvodnosti spomenutih tehnologija i izlučivanje utjecajnih čimbenika koji bi mogli poslužiti kao smjernice u procesu ocjene primijenjenih tehnologija kroz sustav za podršku odlučivanju. Rezultati pokazuju da proizvodnost strojne sječe statistički značajno odstupa između morfološki različitih stabala. U cilju donošenja općih smjernica, ustanovljeno je da je proizvodnost kod CTL tehnologije 25% veća u sastojinama onih stabala koja imaju jedno deblo, kratku krošnju i tanke grane, u odnosu na sastojine stabala koja imaju više debala, dugačku krošnju i deblje grane, ovisno o distribuciji prsnih promjera doznačenih stabala.

KLJUČNE RIJEČI: ručno-strojna sječa, vrste tvrdog drva, studij vremena, radne tehnike, proizvodnost.