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Performance, Capability and Costs of Motor-Manual Tree Felling in Hyrcanian Hardwood Forest

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Abstract – Nacrtak

Motor-manual tree felling is the most labor-intensive component of all harvesting operations and frequently represents a bottleneck in wood production. The study of motor-manual tree felling was carried out in two compartments in the Namkhaneh district of Kheyrud Forest. The objects of this study were as follows: time study of tree felling operations, estimate of chainsaw productivity and costs, development of a regression model in uneven-aged stand using single-tree selection methods. The factors affecting total felling time regression model (increasing order of importance) were DBH of harvested trees, direction of felling regarding the lay and inter-tree distance. The hourly production of chainsaw felling with and without delay time was 56.4 cubic meters per hour (13 tree/hour) and 80.7 cubic meters per hour (19 tree/hour), respectively. Productivity of chainsaw felling increased in relation to tree DBH as power relation. The cost of chainsaw felling with and without delay time was 0.55 and 0.39 USD/m^3, respectively. The cost of felling increased as simple exponential equation when DBH of harvested trees decreased. However, the unit felling cost for chainsaw operation decreased as the tree size increased. Total felling cycle time without delay averaged 3.14 minutes and with delay time it averaged 4.5 minutes. Productivity was more sensitive to DBH than felling direction and inter-tree distance.

Keywords: tree felling, time study, regression model, production, cost

1. Introduction – *Uvod*

Hyrcanian forest in northern Iran is an example of biodiversity, with endemic and endangered species, and a diverse range of economic and social conditions. About 45% of the Hyrcanian forests are located in mountainous areas, where forest lands are not readily accessible with ground-based logging equipments. Felling, limbing and bucking are all done at the stump site. Motor-manual systems are used by workers equipped with chainsaws (Sobhani and Staurt 1991). Chainsaw felling is often associated with large trees and steep or rough terrain. It is used for areas where ground-based machines cannot travel or where the trees are too large for mechanical felling. Due to larger diameter and crowns of hardwoods, and the relatively steep terrain in the Hyrcanian forest, motor-manual tree felling is still the only system used in the region (Sarikhani 2008). The capital investment required for motor-manual felling is several hundred times less than for mechanical felling, and the felling costs per cubic meter are usually lower as well. Despite these differences, other factors such as terrain and timber conditions and total system productivity dominate the choice between the two systems for large contractors (MacDonald 1999, Sessions et al. 2007).

Harvesting starts with the cutting down of trees with hand tools, chain saws, or mechanized felling machines. Felling is the most dangerous part of the harvesting operation (Conway 1976, ILO 1998, Heinimann 2004, Sessions et al. 2007). Larger trees generally must be felled manually with a chainsaw. In Hyrcanian forest regions, trees were large and heavy with huge crowns. They fall with a tremendous force, which can uproot the neighboring trees; and stems may shatter, bounce, and roll uncontrollably. Therefore, motor-manual felling operations are the most hazardous part of harvesting operations for the labor forces in this forest. They are also a major cause of damage to the forest stand and result in the generation of a large amount of wood waste. The objective of the tree felling operation is to fell the tree with minimum damage, to avoid damaging surrounding trees, to minimize soil and water impacts, and to position the tree or logs for the next phase of harvesting. Directional felling is a specific tree-felling technique, in which the direction of fall is determined by the operator prior to cutting. Where possible, trees should be felled in the direction of existing canopy gaps in order to reduce damage to nearby standing timber. In general, trees should be felled either towards or away from skid trails, preferably at an oblique angle to the skidding direction (FAO 1976, Dykstra and Heinrich 1996, MacDonald 1999).

Hartsough et al. (2001) developed the felling time prediction model based on the tabular data of felling time per tree collected on clear cutting of second-growth timber. Kluender and Stokes (1996) developed a nonlinear model to predict felling time for different harvesting prescriptions, using variables as distance from previous tree, proportion of basal area removed and DBH. Lortz et al. (1997) conducted an analysis of southern pine felling with chainsaw and produced several equations for estimating felling time and productivity. They found that factors affecting total felling time were DBH of harvested stems, inter-distance, and harvest intensity. Wang et al. (2004) conducted a time study on central Appalachian hardwood forest consisting of motor-manual felling and cable skidding. They reported that felling time was mainly affected by diameter at breast height and distance between harvested trees. This study showed that productivity of chainsaw felling was 362 ft^3 per productive machine hour (PMH) with a unit cost of \$8.0/100 cubic feet. Rummer and Klepac (2002) conducted a time study to compare two harvesting systems; mechanized and motor-manual felling operations. This study showed that the harvester was about as productive as a manual crew of five. Also, they reported that there is a strong trend of increasing cycle time as tree size increases and a regression equation was developed to predict total cycle time as a function of tree diameter. Li et al. (2006) conducted a simulation study for comparing production and cost of felling among chainsaw, harvester, and feller-buncher. They found that the unit felling cost for chainsaw operation decreased as the tree size increased.

Few previous studies have addressed the production and cost of motor-manual tree felling in Hyrcanian hardwood stands. Nikooy (2007) developed a productivity model for chainsaw felling in Caspian hardwood forests, which included variables such as diameter at breast height and the distance among harvested trees. This study reported that productivity of tree felling with and without delay time was 53 and 67 cubic meters per productive machine hour (PMH), respectively. Behjou et al. (2009) conducted a time study on Hyrcanian forests. They found that felling time per tree was most affected by diameter at breast height and by the distance among harvested trees. The gross and net production rate was 20.6 m^3 and 26.1 m^3 per hour/one person, respectively. The objective of this study was to: conduct a continuous time study on motor-manual tree felling with a chainsaw in a Hyrcanian hardwood forest, employing regression techniques to develop models for elemental times and cycle time of chainsaw felling, and estimate the production rates and costs of chainsaw felling.

2. Study sites and methods – *Mjesto i metode istraživanja*

The research was carried out in two compartments 219 and 223 located in Namkhaneh District within Kheyrud Educational and Research Forest. The altitude ranges from 1 000 to 1 135 m and the forest lies southwest. The slope ranges from 10 to 70% with an average of 40%. The average rainfall ranged from 1 420 to 1 530 mm/year, with the heaviest precipitation in the summer and fall. The average daily temperatures ranged from a few degrees below 0°C in December, January, and February to +25°C during the summer. This area is dominated by natural forests containing native mixed deciduous tree species such as *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Acer velutinum* Boiss., and *Alnus subcordata* (Jourgholami 2013). The management method is mixed un-even aged high forest with single and group selective cutting regime. Trees to be removed are felled, limbed and topped motor-manually. Felled trees are bucked and processed with chainsaws into logs, sawn-lumber and pulpwood. The logs 5 to 15 meter long are extracted by wheeled cable skidders to the roadside landings. The fuel wood is extracted by mules. Also, in steep terrain that cannot be reached by skidders, logs are processed to sawn-lumber and then hauled by mules (Jourgholami 2012). Table 1 summarizes some characteristics of the study site.

Felling was performed using a STIHL chainsaw with 4-hoursepower (hp) engine and bar length of 70 cm (Fig. 1). The field study was conducted from January to February 2011 on Kheyrud Forest during

Table 1 Study site description
Tablica 1. *Mjesto istraživanja*

Compartment *Odjel*	Area *Površina*	Trees per ha *Broj stabala po ha*	Volume *Obujam*	Total felled trees *Ukupan broj posječenih stabala*	Total volume of felled trees *Etat (sječna gustoća)*	DBH of felled trees *Prsni promjer*
	ha		m^3/ha	num. (t/ha) – *broj (stabala/ha)*	m^3 (m^3/ha)	cm
219	27	173	504	270 (10 t/ha)	872.3 (32 m^3/ha)	20–135
223	56	123	301	181 (3 t/ha)	719.5 (13 m^3/ha)	20–135

Table 2 Main work phases that make up total felling time
Tablica 2. *Faze radova sječe*

Work elemental function *Radni zahvati*	Definition – *Opis radnih zahvata*
Walk to tree – *Prilazak stablu*	Begins when the sawyer starts toward the tree to be cut and ends when the sawyer reaches to the tree *Prilazak stablu počinje kada šumski radnik sjekač krene prema doznačenomu stablu i završava kada dođe do njega*
Acquire *Čišćenje okoliša oko stabla i određivanje smjera rušenja*	Begins when the sawyer starts clearing around the tree and decides where the tree will fall and ends when the sawyer is ready to cut the tree *Priprema počinje kada šumski radnik sjekač počne čistiti okoliš oko stabla, zatim odlučuje o smjeru rušenja stabla te završava kada je radnik spreman za sječu stabla*
Undercut – *Izrada zasjeka*	Begins when the sawyer starts to make a wedge-shaped notch in the base of the tree to ensure that it accurately faces the felling direction and ends when the sawyer starts backcut *Radni zahvat započinje izradom kosoga reza zasjeka, u odabranom smjeru rušenja stabla, a završava kada je sjekač spreman za potpiljivanje*
Backcut – *Potpiljivanje*	Begins when the sawyer starts cutting the opposite side of the direction of fall and ends when the tree hits the ground *Radni zahvat počinje prilikom prerezivanja stabla sa suprotne strane od zasjeka i završava kad se stablo sruši na zemlju*
Wedging – *Zabijanje klinova*	Begins when the co-sawyer starts to enter the wedge-shaped blade to the cutting gap and ends when the tree falls in the predetermined direction *Radni zahvat započinje kada pomoćni radnik sjekač počne postavljati klinove u potpiljak te završava kad se stablo sruši na zemlju*
Refuel and Service *Punjenje goriva, maziva i popravak*	Maintenance and refueling – *Održavanje motorne pile i punjenje goriva i maziva*
Delays – *Zastoji*	Personal delay, Technical delay, and Operational delay – *Osobni prekidi rada, tehnički prekidi rada i povremeni radovi*

winter; cold occasionally affected worker utilization percentages. The power-saw team normally consists of three men: a feller, an assistant, and a helper. Time and operational variables were measured using a stopwatch and recorded on paper (Bjorheden and Thompson 1995, Wang et al. 2004). A work cycle for each operation consisted of certain elemental functions and factors. The time for each function and value of each factor were measured in the field. Elemental time functions for chainsaw felling are shown in Table 2.

Harvesting factors or operational variables for chainsaw felling measured in the field include distance to tree (cm), tree species, diameter at breast height (DBH) (cm), walk to tree slope (%), slope at tree stump (%), and direction of felling: code 1: felling to lean; code 2: felling sideways to the lean (0° to 90°); code 3: felling opposite the lean (90° to 180°)). A total of 233 cycles for chainsaw felling were observed in the field. Local volume equations of Namkhaneh district were used to compute the volume of felled trees. The SPSS 14.0 statistical program was applied to develop regression equation of time consumption. A regression analysis with the stepwise method between operational variables (independent variables) was per-

Fig. 1 Starting to undercut (A and B), cutting the backcut and wedging (C) in the study area

Slika 1. *Šumski radnik sjekač započinje izradu zasjeka (A i B), potpiljivanje i zabijanje klinova (C)*

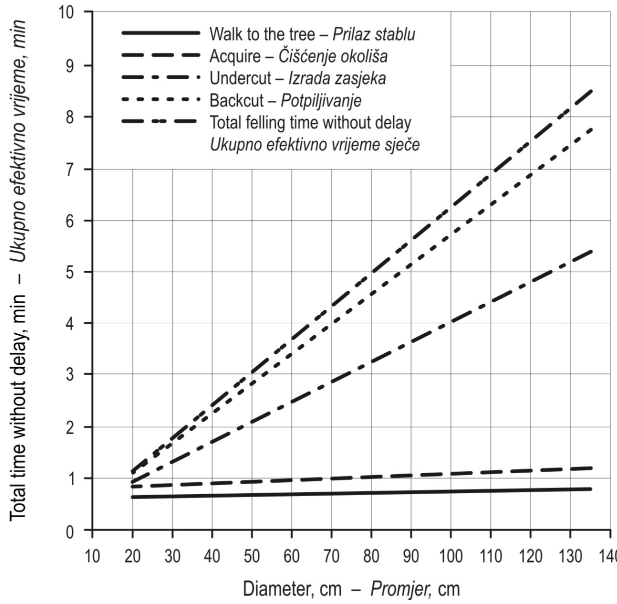

Fig. 2 Effect of DBH on felling time without delay of tree felling

Slika 2. *Utjecaj prsnoga promjera na vrijeme sječe stabla, bez radnih zastoja*

formed on the time study data collected for chainsaw, to determine independent variables that were significant in estimating total felling time ($p = 0.01$). Regression techniques were also employed to develop models for elemental times, felling cycle time and productivity of chainsaw felling.

Total felling time was analyzed in stages (Lortz et al. 1997). First, each work elemental function (phase) was fit to a linear equation ($Y = a + bX$) using DBH as independent variable. Then, other operational variables were added to the model to show how these factors influence the felling time, and to give a more reliable model of motor-manual felling operation.

3. Results and discussion – *Rezultati i rasprava*

DBH of felled trees ranged from 20 to 135 centimeters and averaged 52.3 centimeters, while the volume per felled tree was between 0.2 to 29.7 cubic meters with an average of 4.27 cubic meters (Table 3). Distance between harvested trees varied from 2 to 105 meters with an average of 25.4 meters. A felling cycle consists of the following elements: walk to tree, acquire, undercut, backcut, wedging, refuel and service, and delay times. Total felling time varied from 0.6 to 29.65 minutes with an average of 4.5 minutes, while total felling time without delay ranged between 0.6 to 10.1 minutes with an average of 3.14 minutes per cycle (Table 3).

Table 3 Statistics of operational variables of motor-manual felling in the field study
Tablica 3. *Statistika operativnih varijabli u provedenom istraživanju ručno-strojne sječe*

Factor	Delay free time *Vrijeme bez zastoja*	Refuel & service *Točenje goriva i popravak*	Wedging *Zabijanje klinova*	Backcut *Izrada završnoga reza*	Undercut *Izrada zasjeka*	Acquire *Čišćenje okoliša i određivanje smjera rušenja*	Walk *Hod do stabla*	Volume *Obujam*	Tree diameter *Prsni promjer stabla*
	min							m^3	cm
Mean – *Srednja vrijednost*	3.14	0.15	0.1	0.74	1.25	0.23	0.66	4.22	52.34
Minimum	0.6	0	0	0.13	0.06	0.05	0.09	0.22	20
Maximum	10.1	3.5	4.17	3.49	5.72	2.15	2.82	29.7	135
Std. dev.	1.95	0.56	0.49	0.62	1.01	0.21	0.43	5.23	24.59
Factor	Direction of felling *Smjer obaranja*	Slope at stump *Nagib kod panja*	Walk to tree slope *Nagib tijekom hoda do stabla*	Inter-tree dis. *Udaljenos između doznačenih stabala*	Total felling time *Ukupno vrijeme sječe*	Total delay *Ukupni prekidi rada*	Oper. Delay *Operativni prekidi rada*	Tech. Delay *Tehnički prekidi rada*	Pers. Delay *Osobni prekidi rada*
	code* *šifra**	%		m	min				
Mean – *Srednja vrijednost*	1.31	26.07	28.5	25.43	4.5	1.36	0	0.17	1.18
Minimum	1	5	5	2	0.6	0	0	0	0
Maximum	3	70	65	105	29.65	24.36	0	20.21	24.36
Std. dev.	0.55	15.29	14.36	16.6	4.99	4.16	0	1.48	3.9

*code (felling direction as described in text) – *šifra (odabrani smjer rušenja stabla kako je opisano u tekstu)*

Time of the walk to the tree averaged 0.66 minutes and ranged between 0.09 to 2.82 minutes. Since the walk to the tree is directly related to stand density and harvesting method (Single-selection method), it was significantly different depending on the distance between felled trees. Acquire time averaged 0.23 minutes and ranged between 0.05 and 2.15 minutes per cycle. Time of undercut varied from 0.06 to 5.72 minutes with an average of 1.25 minute per cycle s. Backcut time ranged from 0.13 to 3.49 minutes and averaged 0.74 minutes per cycle. Some trees needed no wedging time. However, a maximum of 4.17 minutes was taken to direct large trees. Refuel and service time averaged 0.15 minutes per cycle. A total of 55 delays was observed during motor-manual felling in the field study. The delay times were ranged from 0 to 24.36 and averaged 1.36 minutes per cycle.

The relation between tree size and total cycle time is shown in the scatter diagram in Fig. 2. There is a strong trend of increasing cycle time as tree size increases. A regression equation was developed to predict total cycle time as a function of tree diameter. Other independent variables were tested and were not significantly related to the total cycle time (Fig. 3–5).

The stepwise analysis has revealed that tree diameter (DBH) significantly affects the felling cycle time (Fig. 3). Therefore, we have developed a regression model of the total felling time without delay using tree diameter, direction of felling, and inter-distance of felled trees as an independent variable (Eq. 1). On the other hand, the total felling time was best described by DBH, direction of felling, and distance between felled trees. Statistical significance was checked by an

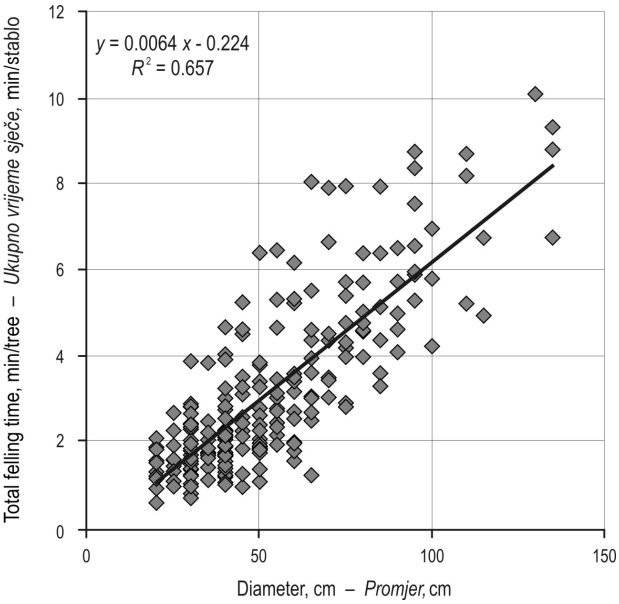

Fig. 3 Relation between DBH and total cycle time without delay for felling per cycle

Slika 3. *Odnos između prsnoga promjera i ukupnoga vremena sječe, bez radnih zastoja*

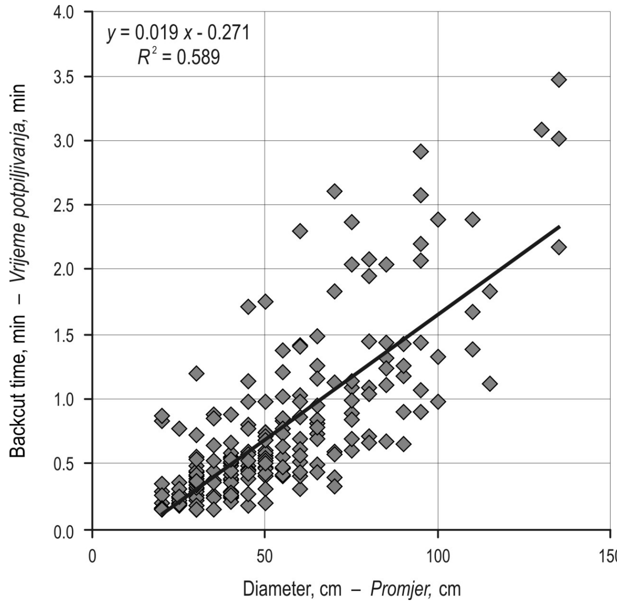

Fig. 5 Effect of DBH on backcut time of tree felling per cycle

Slika 5. *Utjecaj prsnoga promjera na vrijeme potpiljivanja stabla*

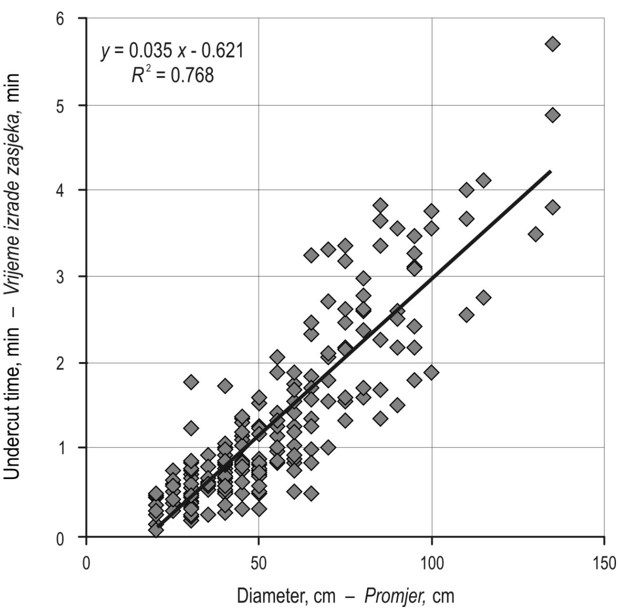

Fig. 4 Effect of DBH on undercut time of tree felling per cycle

Slika 4. *Utjecaj prsnoga promjera na vrijeme izrade zasjeka*

F-test of the overall fit and t-tests for individual parameters (Table 4).

$$T = -1.1997 + 0.05844\mathrm{DBH} + 0.63097\mathrm{DF} + 0.001778\mathrm{D} \quad (1)$$

Table 4 ANOVA for regression model developed for motor-manual tree felling

Tablica 4. *ANOVA za regresijski model razvijen za ručno-strojnu sječu*

Factor	*SS*	*df*	*MS*	*f*	*Sig.*
Regression	621.44	3	2078.15	182.2	<0.0001
Residual	260.3	229	1.14		
Total	881.74	232			

Where:

T = total felling time without delay (min)
DBH = diameter at breast height (cm)
DF = direction of felling (1–3 or 0°–180°)
D = distance between felled trees (m)
R^2 = 0.705, Adjusted R-square = 0.701; Number of observations = 233

The multiple correlation coefficient of the model shows that 70.5% of the total variability can be explained by the model. The significance level and F-value in the table with the analysis of the model variance confirms that the model makes sense at the probability level of 0.05.

The production of felling with chainsaw can be obtained by using the production and time data as follow:

$$Production = \frac{TFV}{TFV}$$

Where:

TFV = total felling volume, m^3

TFT = total felling time, hour

The hourly production (m^3/hr) with delay time was 56.34 m^3/hour. The measured production for motor-manual felling without delay times was 80.7 m^3/hour. Hourly production of felling without delay times was higher than production (m^3/hour) with delay times. Also, the hourly production of chainsaw felling with and without delay time was 13 trees per hour and 19 trees hour, respectively. The relation between tree size and felling production is shown in the scatter diagram in Fig. 6. There is a strong trend of increasing production as tree size increases.

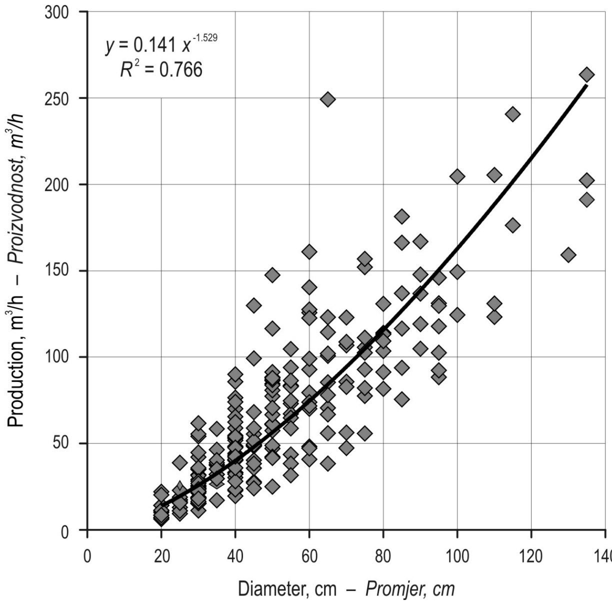

Fig. 6 Effect of DBH on felling productivity

Slika 6. *Utjecaj prsnoga promjera na proizvodnost sječe*

We calculated the hourly cost ($/hr) of motor-manual felling using the cost estimation model developed by the Forest, Range and Watershed Management Organization of Iran (1999). A purchase price of USD 1 400 was used in the chainsaw cost estimation model, and the annual interest rate of 18.5%. A chainsaw life of 3 years was assumed. Insurance and tax rate and utilization rate were set at 5% and 83%, respectively. The hourly machine cost was estimated at USD 31.26. Table 5 summarizes the estimates of machine costs for chainsaws.

As a result, the average felling cost per cubic meter, including the delay time, was USD 0.55/m^3, while the average felling cost without delay was estimated at USD 0.39/m^3. The cost of chainsaw felling with and without delay time was 2.34 and 1.64 USD per tree, respectively. Approximately 25% of the total operating hours were identified as delay times during the time study, which results in an average machine utilization rate of 75%.

The effect of each variable used in the model on the felling time was studied by changing one variable in its range and retaining the other variables constant at their average. Fig. 7 shows the effect of operational variables on felling costs. Increasing tree diameter and direction of felling will increase felling costs per cycle. The effect of tree size on unit cost of motor-manual felling tree is shown in Figure 8. DBH classes of 20 to 50 centimeters have a dramatic effect on felling costs,

Table 5 Calculation of motor-manual felling costs

Tablica 5. *Izračun troškova ručno-strojne sječe*

Cost elements *Vrsta troška*	Fixed costs – *Fiksni troškovi*				Operating costs – *Materijalni troškovi*				Hourly labor cost *Trošak radnoga sata*	Total hourly machine rate *Ukupni trošak radnoga sata stroja*
	Depreciation *Amortizacija*	Interest *Kamata*	Tax and insurance *Porez i osiguranje*	Subtotal (Fixed) *Ukupni fiksni troškovi*	Maintenance and repair *Održavnje i popravak*	Fuel and lubricant *Gorivo i mazivo*	Chain and file *Lanac i oštrač lanca*	Subtotal (Operating) *Ukupni materijalni troškovi*		
USD/hour *USD/satu*	0.47	0.2	0.07	0.73	0.47	13	1.06	14.53	16	31.26

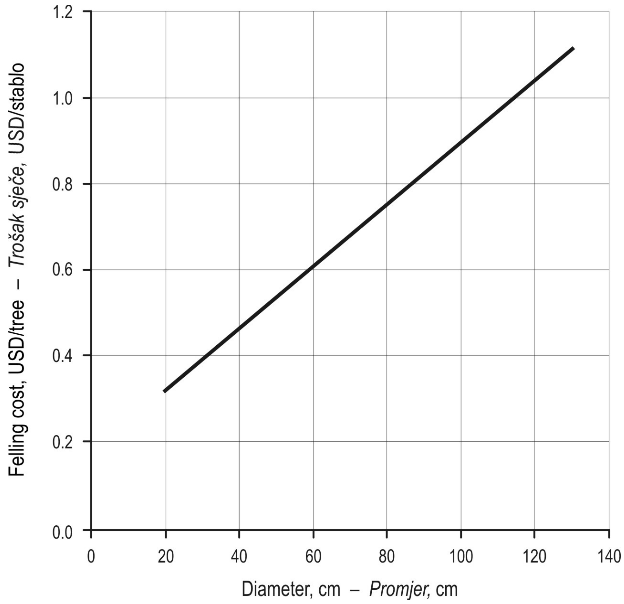

Fig. 7 Effect of tree diameter (DBH) on felling costs
Slika 7. *Utjecaj prsnoga promjera na troškove sječe*

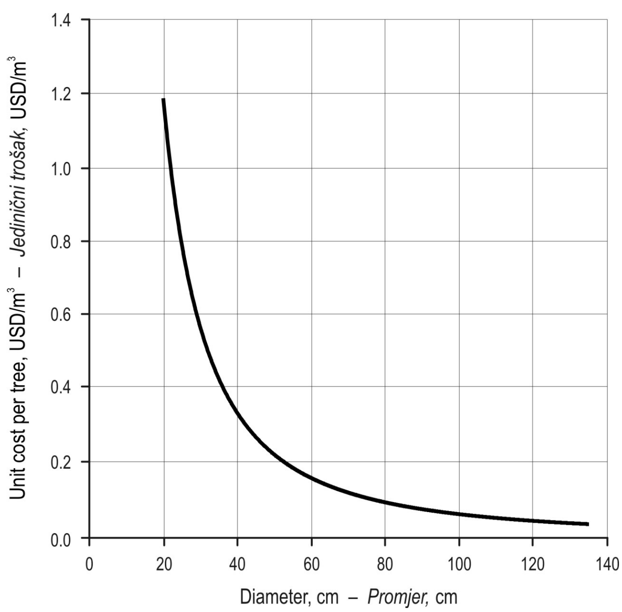

Fig. 8 Effect of tree diameter on unit cost of motor-manual tree felling
Slika 8. *Utjecaj prsnoga promjera na jedinične troškove sječe*

ranging from USD 1.2 to 0.2 per m^3. With the classes above 50 cm class, the felling costs for the chainsaw changed constantly.

During the study period, felling time was divided into elemental time functions (work phases) as shown in Fig. 9. On average, during a cycle most time was spent on undercut, which accounted for 27.9% of the total time. Personal delay (rest and meal time) accounted for approximately 26.3% of the time. Backcut and walk to tree accounted for 16.5% and 14.6% of the total cycle time, respectively. Acquire accounted for less than 5% of the total cycle time. Technical delay accounted for only 3.9% of the total time, while refuel and service and wedging time accounted for about 3.4% and 2.3%, respectively.

Undercut, backcut and delay time were the most important time-consuming elements in felling. This suggests that the productivity could be increased by diminishing the time consumption of these elements. Delay time is an inseparable part of each work phase in harvesting in Iran. Delay time accounted for approximately 30% of gross-effective hour. Technical delays, such as sharpening and dealing with the chain of a chainsaw breaking, accounted for approximately 4% of the delay time. One of the reasons for a long delay time was the use of old and obsolete equipment, unsuitable and incorrect filling of the chain saw (Mousavi 2009).

Operational delay accounted for the largest share that needs to be considered. Operation delay may relate to management, supervision, and equipment

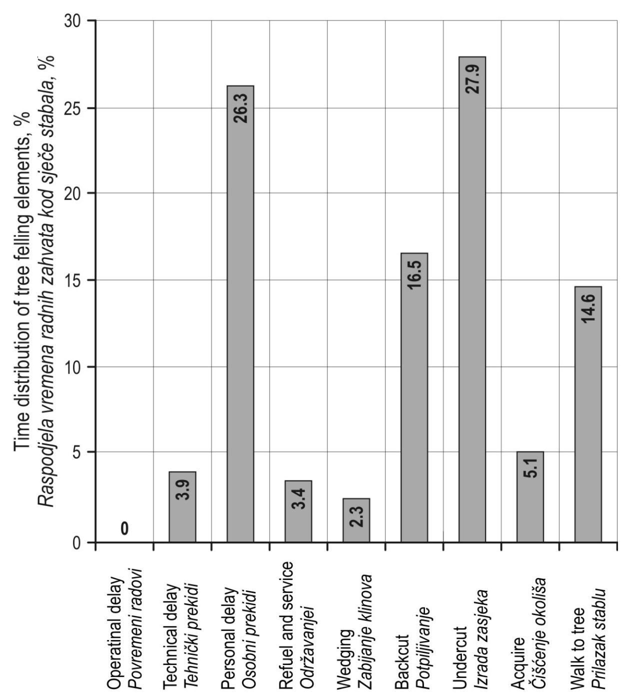

Fig. 9 Percentage of time distribution of tree felling elements
Slika 9. *Postotna distribucija vremena radnih zahvata prilikom sječe stabala*

availability. A felling group might not have had all the necessary tools needed for work, which caused a prolonged delay as they had to borrow the tools from the neighboring groups. Activities such as the chain breaking and filing as well as pinching in the kerfs can be part of the working time (Sarikhani 2008), however, in this study it is considered as a technical delay. If we take into account these activities as a part of effective working hour, productivity of felling decreases approximately by 3.6%. Walking is the first element of the felling work cycle. Silvicultural treatment is one of the most important factors influencing time consumption of walking. In the single tree selection method, there were more trees in the forest than in the shelter wood and clear cutting method, and hence more time was required (Lortz et al. 1997, Mousavi 2009). In this study, only 14% of the gross-effective hour was related to walking time.

In some areas, the skid trails were not marked, so the operator was free to choose the direction. It may increase skidding time and cost. It is recommended to mark skid trails before felling (Nikooy 2007, Mousavi 2009). The higher percentage of backcut is related to the use of a wedge to lead the tree in the specified direction in order to prevent damage to the residual stand and breakage to the tree being felled. The results showed that the stump diameter, direction of felling and distance were the most important variables affecting the felling time. Tree diameter and inter-tree distance influenced the time consumption of felling, productivity, and unit cost of felling. A study by Kluender and Stokes (1996) showed similar results. They found that tree diameter is the most important factor in estimating the felling time, while the distance between trees and harvesting intensity were also important.

However, productivity of felling may be influenced by the operator skills, silvicultural method, tree species, stand composition, undergrowth trees and seedlings, weather condition, coldness of weather, age and brands of chainsaws, chain condition, and lean of the tree as well as slopes (Nikooy 2007, Sarikhani 2008, Mousavi 2009). However, the influences of all these factors were not documented in this study but they were mentioned by Conway (1976).

4. Conclusion – *Zaključak*

Motor-manual tree felling is a highly variable operation. There are many factors influencing the felling productivity. This paper identifies the most significant variables that should be recognized prior to harvesting. It has been proved that the stump diameter of the tree is the most influential factor affecting time consumption and productivity of felling. Inter-tree distance also influences the time consumption and productivity of felling. The productivity of felling trees with a large diameter is higher than the productivity of felling trees with a small diameter.

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Sažetak

Izvedba, mogućnosti i troškovi ručno-strojne sječe stabala u šumi tvrdih listača Hyrcanian

Zbog velikih promjera krošanja te zbog prilično strmoga terena u hirkanskim šumama stabla se sijeku isključivo ručno-strojnom metodom. Ciljevi su ovoga istraživanja: provesti studij rada i vremena ručno-strojne sječe u tvrdim listačama, primjenom regresijskih funkcija razviti modele vremena radnih zahvata ručno-strojne sječe te procijeniti proizvodnost i troškove ručno-strojne sječe. Istraživanje je provedeno u odjelima 219 i 223 koji se nalaze u okrugu Namkhaneh unutar nastavno-pokusne šume Kheyrud. Za sječu je stabala korištena motorna pila STHIL s četiri konjske snage te vodilicom od 70 cm. Istraživanje je provedeno zimi od siječnja do veljače 2011. godine. Zimsko vrijeme, osobito hladnoća, ponekad utječu na radni učinak radnika sjekača. Radni se ciklus sastojao od određenih radnih zahvata i drugih čimbenika. Vrijeme za svaki radni zahvat i vrijednost svakoga čimbenika mjereno je na istraživanom radilištu. Čimbenici koji utječu na sječu ili operativne varijable za sječu koje su mjerene u istraživanju su udaljenost od stabla (cm), vrsta drveća, prsni promjer (cm), nagib po kojem se radnik kreće prilikom dolaska do stabla (%), nagib terena kod panja (%), smjer rušenja stabla. Ukupno su snimljena 233 radna ciklusa sječe stabla. Za izradu regresijskih jednadžbi korišten je statistički program SPSS 14.0. Rezultati provedene analize ukazuju na povećanje radnoga ciklusa s povećanjem dimenzija stabla. Postupna analiza podataka pokazala je značajan utjecaj prsnoga promjera na vrijeme sječe, te je stoga razvijen regresijski model za izračun ukupnoga vremena sječe, bez zastoja, na osnovi prsnoga promjera stabla, smjera rušenja te međusobne udaljenosti doznačenih stabala. Proizvodnost (m^3/h) sa zastojima rada iznosila je 56,34 m^3/h. Izmjerena proizvodnost za ručno-strojnu sječu, bez zastoja rada, iznosila je 80,7 m^3/h. Proizvodnost (m^3/h) bez zastoja rada iznosila je više nego proizvodnost sa zastojima rada. Povećanje dimenzija stabala značajno utječe na povećanje proizvodnosti. Kao krajnji rezultat analize prosječni trošak ručno-strojne sječe, sa zastojima rada, iznosio je 0,55 USD/ m^3, dok je prosječan trošak ručno-strojne sječe bez zastoja rada iznosio 0,39 USD/ m^3. Povećanje prsnoga promjera stabla te smjer rušenja utjecat će na povećanje troškova ručno-strojne sječe po proizvodnom ciklusu. Stabla prsnih promjera od 20 do 50 cm imaju značajan utjecaj na troškove ručno-strojne sječe, koji se kreću u rasponu od 1,2 do 0,2 USD/ m^3. Na vrijeme izrade zasjeka, završnoga reza te vremena zastoja otpada najveći dio vremena radnoga ciklusa. U ovom su radu predstavljene najvažnije varijable koje utječu na ručno-

strojnu sječu te ih je prije provođenja radova ručno-strojne sječe potrebo vrednovati. Dokazano je da su promjer panja i udaljenost između doznačenih stabala najutjecajniji čimbenici potrošnje vremena i proizvodnosti prilikom sječe. Proizvodnost pri sječi stabala većih promjera veća je nego pri sječi stabala manjih promjera.

Ključne riječi: sječa stabala, studij rada i vremena, regresijski model, proizvodnost, troškovi

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