Forwarding productivity in Southern Austria

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Abstract – Nacrtak

Forwarders are common machines in the cut to length harvesting system. A general regression model for predicting the time of forwarding was developed using 82 working cycles of two kinds of machines in downhill timber extraction. Using stepwise regression, variables such as forwarding distance, slope, type of forwarder and piece volume were significantly entered to the model. Increasing forwarding distance increases the forwarding time. However, if piece volume and slope of the trail increase, the forwarding time decreases. The average forwarding production was estimated to about 17.9 m^3/PSH_0 (Productive System Hours) while mean load per trip was 10.04 m^3 and average forwarding distance was 97 m.

***Keyword**: forwarder, productivity, cost, model, regression*

1. Introduction – *Uvod*

Cut-to-length systems generally comprise two machines: a harvester and a forwarder. In Austria, 17% of the timber is extracted by forwarders (www.lebensministerum.at). Many factors can affect the productivity of forwarders. Kellogg and Bettinger (1994) in Oregon (USA) developed a productivity model for forwarding, which included variables such as assortments (pulpwood, sawlog or mixed loads), volume per load, travel distance of unloaded forwarder, travel distance during loading and travel distance of loaded forwarder to landing. The productivity of forwarder is strongly correlated to stand type, average extraction distance, timber volume density at the strip road and load volume of the forwarder (Tufts and Brinkeer 1993, Kuitto et al. 1994).

In other studies carried out in central Finland for different cutting sites, harvesting density on strip roads, the average extraction distance, forwarder load capacity, timber assortment and bunching of assortments on the strip road had an effect on the haulage system (Nurminen et al. 2006).

The working method can also affect the productivity of harwarders as well as variables such as load volume, tree size and extraction distance (Andersson and Eliasson 2004).

A study of short-wood forwarding carried out in Northern Spain resulted in a productivity of 6 to 15 t/SMH (Spinelli et al. 2003). Akay and Sessions (2001) reported the production rates in USA for small, medium and large size of forwarder as 0.51, 0.6 and 0.69 m^3/h, respectively.

Other productivity studies resulted in the range of 8 to over 20 t/SMH, depending on the model and working conditions (UK Forestry Commission 1995, Gullberg 1997, Martin dos Santos et al. 1995, Saunders 1996, Goglia et al. 1999, Horvat et al. 1990).

Cordeo et al. (2006) used GPS technology to monitor cut-to-length (CTL) system in Chile. In this method, by capturing the position of machine, it was possible to generate surface progress grids, which when combined with inventory grids, result in yield information by surface and time unit. The hourly production rate was 35.8 m^3 in clear cut sites.

Due to increasing forwarding system in the forests of central Europe, it is necessary to study the productivity and cost of this system to give planners a useful tool for harvest planning. There is no general time predicting model available for forwarders in Austria. Therefor this study was carried out to de-

Fig. 1 Ponsse Buffalo Dual Harwarder

Slika 1. *Harvarder Ponsse Buffalo Dual*

velop such a model using time study databases on two types of forwarders. Verification of the model was done. The effect of variables on the time of forwarding is also presented in this paper.

2. Method of study – *Metoda istraživanja*

2.1 Site of study – *Mjesto istraživanja*

The first study was carried out in Weiz in Steiermark in southern Austria. In this area a Ponsse Buffalo Dual forwarder was used in a mixed stand of spruce, fir, larch and pine. The terrain slope was moderate (11%).

Table 1 Description of study sites

Tablica 1. *Opis mjesta istraživanja*

Stand – *Sastojina*	1	2
Area, ha – *Površina*, ha	2.27	1.83
Slope, % – *Nagib terena*, %	11	39
Stand age, years – *Dob sastojine*, godine	70–130	90
No. of trees per hectare – *Broj stabala po ha*	1089	729
Growing stock, m^3/ha – *Drvna zaliha*, m^3/ha	510.4	646
No. of harvested trees – *Br. posječenih stabala*	1073	470
Harvested volume, m^3 – *Posječeno drvo*, m^3	331.8	513
Tree volume, m^3 – *Srednji obujam stabla*, m^3	0.31	0.7
Harvesting intensity, % – *Intenzitet sječe*, %	28.7	45
Number of trails – *Broj traktorskih vlaka*	15	5
Length of trails, m – *Duljina vlaka*, m	40–200	190–235
Time of harvesting – *Vrijeme sječe*	Spring – *Proljeće*	

By the Dual concept of a combined harvester-forwarder system, known as the harwarder, trees are felled, delimbed, topped, and bunched using the harvesting head of the harwarder in pre-planned machine trails. The operator then fits the load bunk for forwarding the logs to the roadside landing. The grapple head is used to load the logs onto the bunk of the machine. For the machine specifications of the harwarder refer to Table 1.

Table 2 Specifications for the Ponsse Buffalo Dual Harwarder

Tablica 2. *Tehničke značajke harvardera Ponsse Buffalo Dual*

Vehicle technical data – *Tehnički podaci vozila*	
Engine – *Motor*	Mercedes-Benz OM906LA
Power – *Snaga*	180 kW
Torque – *Moment*	900 Nm @ 1400 min^{-1}
Pump capacity – *Obujam pumpe*	100 cm^3
Fuel tank volume *Obujam spremnika goriva*	130 L
Length – harvester *Duljina kad se koristi kao harvester*	8850–9150 mm
Length – forwarder *Duljina kad se koristi kao forvarder*	9400–9950 mm
Width (600/700 tires) Širina (gume 600/700)	2670–2810 mm
Ground clearance – *Klirens*	690 mm
Tare mass of harvester *Masa praznoga harvestera*	15700 kg
Tare mass of forwarder *Masa praznoga forvardera*	16400 kg
Load capacity – *Nosivost*	14000 kg
Length of loading space *Duljina tovarnoga prostora*	4040–4590 mm
Extension of loading space *Produljenje tovarnoga prostora*	0–700 mm
Harvesting head – *Sječna glava*	
Harvesting head – *Harvesterska glava*	Ponsse H53
Power – *Snaga*	45 kW
Length – *Duljina*	64 cm
Felling diameter – *Sječni promjer*	52 cm
Feed force – *Posmična sila*	18 kN
Feed speed – *Posmična brzina*	4 m/s
Number of delimbing knives *Broj noževa za kresanje grana*	5
Measuring system – *Mjerni sustav*	Ponsse Opti 4G

Table 3 Specification of Gremo 950R Forwarder
Tablica 3. *Tehničke značajke forvardera Gremo 950R*

Engine – *Motor*	DEUTZ Type BF4M 1013 EC
Power – *Snaga*	111 kW
Pump capacity – *Obujam pumpe*	100 cm^3
Hydraulic tank volume – *Obujam spremnika ulja*	100 L
Fuel tank volume – *Obujam spremnika goriva*	110 L
Tyre dimension – *Dimenzije guma*	600/50-22.5
Load capacity – *Nosivost*	10000 kg
Boom – *Dizalica*	Loglift type 51F
Range – *Doseg*	6.5 m
Lifting capacity – *Podizni moment*	59 kNm
Length – *Duljina*	7895 mm
Width – *Širina*	2600 mm
Height – *Visina*	3445 mm
Turn radius – *Polumjer okretanja*	12.7 m
Ground Clearance – *Klirens*	580 mm
Tare mass of forwarder – *Masa praznoga forvardera*	11185 kg

The second site of study was near to Muerzzuschlag in Steiermark. The mixed species stand consisted of spruce, larch and fir. A Gremo 950R forwarder was used to extract logs that had been processed and piled by a harvester. The terrain slope was 39%. In steep terrain, this forwarder would use a cable fixed to a standing tree to allow safe operation on steep trails (Wratschko 2006).

The general stand and terrain characteristics on both sites are presented in Table 1. According to information from the forest office in Steirmark, the harvesting density was 100 m^3/ha with a mean DBH of 25 cm.

2.2 Data collection – *Prikupljanje podataka*

A continuous time study method was used in both production studies using an electronic EG20 timer. A typical work cycle included loading, travel loaded, unloading and travel empty.

Loading element included the time used to load the logs for one trip. Travel loaded was defined as the time to move a loaded machine to the landing. Unloading included the time spent to unload the logs on the landing and travel empty consisted in the time to move empty from the landing to loading site. The delays of more or less 15 minutes were recorded as well as miscellaneous delays in each working cycles.

The same variables were used at both study sites. Forwarding distance, piece volume, total load volume and slope were recorded during the data collection. Data for 82 working cycles were collected.

It was assumed that forwarding time was a function of forwarding distance, piece volume, slope of trail and type of forwarder. Two time databases were used to develop the time prediction model using stepwise multiple regression.

3. Research results – *Rezultati istraživanja*

3.1 Productivity – *Proizvodnost*

The observed productivity was 17.9 m^3/PSH$_0$ and the average load per cycle was 10.04 m^3. The average loaded and empty travel speeds of the forwarder were 35.9 m/min (0.6 m/s) and 26.3 m/min (0.45 m/s), respectively. Loaded travel was in a downhill direction which resulted in a higher speed than travel empty.

Using the system cost for the Buffalo Dual Harwarder of 120 EUR/h (Affenzeller 2005), the average forwarding cost was estimated to 6.72 EUR/m^3.

3.2 Delays – *Prekidi*

The percentage delay times and time for fixing and opening the cable, relative to total time of working for each forwarder type is presented in Table 5.

The total number of delays was greater for the Gremo 950R forwarder than for Ponsse Buffalo Dual Harwarder. The Gremo 950R forwarder had greater number of delays exceeding 15 minutes, while Ponsse Buffalo Dual Harwarder had greater number of short delays.

3.3 Model – *Model*

SPSS software was used for processing the stepwise multiple regression. Stepwise multiple regres-

Table 4 Worktime delays
Tablica 4. *Prekidi rada*

Forwarder – *Forvarder*	Gremo	Ponsse
Delays – *Prekidi* (<15min)	5.87 %	10.6 %
Delays – *Prekidi* (>15min)	11.87 %	5.49 %
Miscellaneous delays – *Slučajni prekidi*	–	0.51 %
Total delays – *Prekidi ukupno*	17.74 %	16.6 %
Fixing the cable – *Postavljanje užeta*	0.25 %	–
Opening the cable – *Odvezivanje užeta*	0.85 %	–

Table 5 ANOVA table – Overall goodness of fit
Tablica 5. *Analiza varijance – Testiranje značajnosti modela*

	Sum of Squares *Zbroj kvadrata*	Degree of freedom *Br. stupnjeva slobode*	Mean Square *Varijanca*	*F*	Significance *Značajnost*
Regression model – *Regresijski model*	2805.529	4	701.382	8.817	.000
Residual – *Ostatak*	5966.085	75	79.548		
Total – *Ukupno*	8771.614	79			

sion assumes that if any variable has a significant effect on the Residual Mean Squares (RMS) of the model, it will be included in the model. Forwarding distance, piece volume, type of machine and slope were all significant variables at $\alpha = 0.05$.

The following forwarding model was determined on the basis of 82 recorded working cycles:

$$t = 81.293 - 47.886 \times V - 46.795 \times F + \\ + 0.076 \times L - 1.189 \times I$$

where:

t – forwarding time, min/cycle
V – piece volume, m^3/pcs.
F – type of machine
L – forwarding distance, m
I – slope (inclination) of skid trail, %

The value for the Ponsse Buffalo Dual Harwarder is 1 and the value of 0 is considered for Gremo 950R forwarder. The multiple correlation coefficient (R^2) of 0.32 is interpreted as 32% of total variability, which

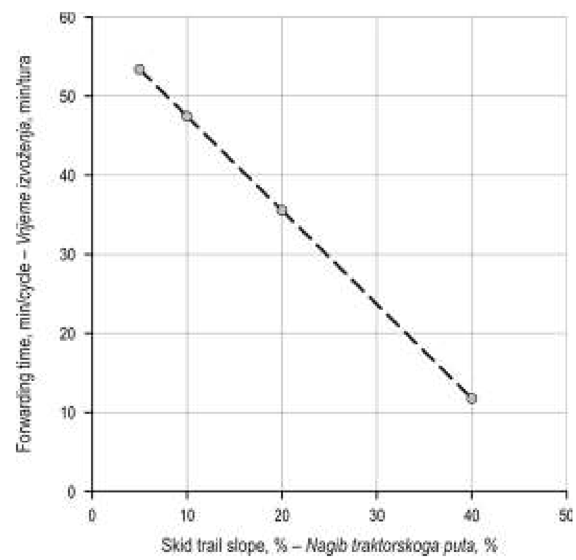

Fig. 3 Cycle time vs. skid trail slope
Slika 3. *Ovisnost vremena turnusa o nagibu vlake*

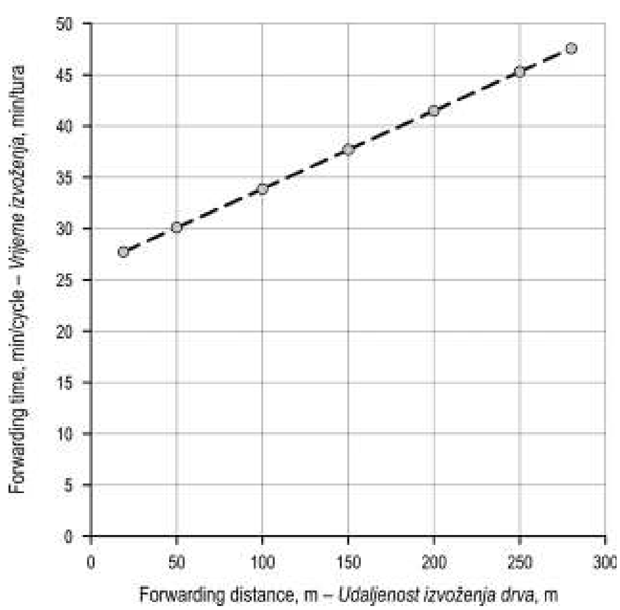

Fig. 2 Cycle time vs. forwarding distance
Slika 2. *Ovisnost vremena turnusa o udaljenosti izvoženja*

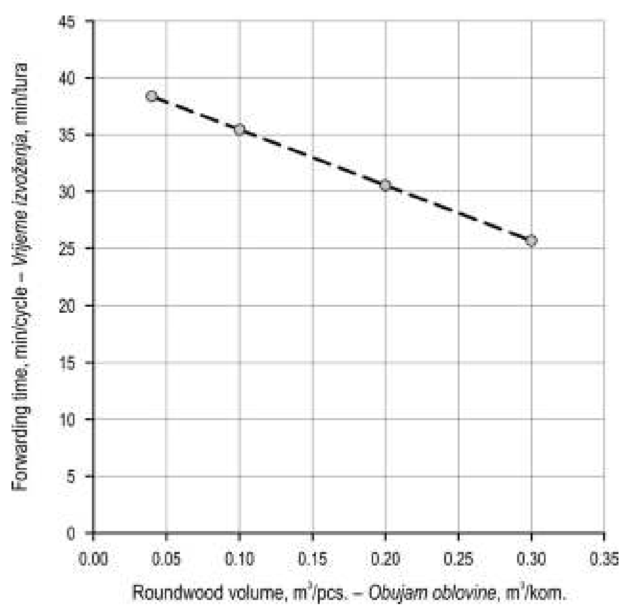

Fig. 4 Cycle time vs. piece volume
Slika 4. *Ovisnost vremena turnusa o obujmu komada*

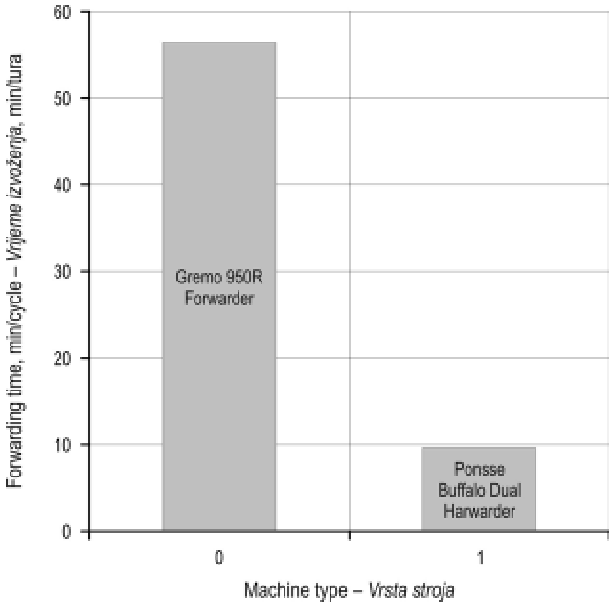

Fig. 5 Cycle time vs. type of machine

Slika 5. *Ovisnost vremena turnusa o tipu vozila*

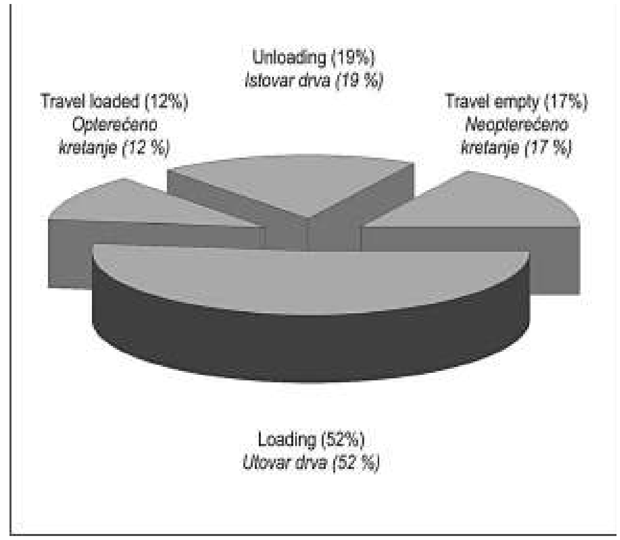

Fig. 6 Percentage of each work component in the cycle time

Slika 6. *Udjeli pojedinih sastavnica rada u vremenu turnusa*

is explained by the regression equation. The significant level of ANOVA (0.000) shows that the model is significant at $\alpha = 0.05$ (Table 5).

The effect of each variable on forwarding time was studied by changing one variable while holding the other variables constant at their mean value. Forwarding time includes travel empty, loading, travel loaded, and unloading.

Figures 2, 3, 4 and 5 show the effect of forwarding distance, slope of skid trail, piece volume and type of machine on forwarding time respectively within the recorded range of variables. In Figure 6, the percent of time spent on each element of the forwarding cycle is shown. The most time is spent loading the logs. Table 6 presents the summary statistics.

4. Conclusions – *Zaključci*

The variables such as forwarding distance, piece volume, type of machine and slope of the skid trail were entered into the general model for predicting forwarding time as significant variables, which can be applied in logging planning. Increasing forwarding distance will increase forwarding time, but if piece volume and downhill slope increase, the forwarding time decreases.

Table 6 Summary statistics of parameters

Tablica 6. *Statistički podaci istraživanih parametara*

Parameter *Parametar*	Maximum *Najveće opažanje*	Mean *Aritmetička sredina*	Minimum *Najmanje opažanje*
Travel Empty, min/cycle – *Neopterećeno kretanje vozila*, min/tura	18.67	5.76	0.4
Loading, min/cycle – *Utovar drva*, min/tura	42.24	17.23	2.78
Travel Loaded, min/cycle – *Vožnja opterećenoga forvardera*, min/tura	10.72	4.22	0.35
Unloading, min/cycle – *Istovar drva*, min/tura	15.31	6.5	0.97
Cycle time, min/cycle – *Vrijeme turnusa*, min/tura	57.68	33.72	8.9
Forwarding distance, m – *Udaljenost izvoženja*, m	280	96.64	4
Slope of skid trail, % – *Nagib traktorske vlake*, %	40	21.62	5
Load volume, m^3/cycle – *Obujam tovara*, m^3/tura	18.7	10.04	1.37
Piece volume, m^3/pcs. – *Obujam komada*, m^3/kom.	0.49	0.14	0.04

Follow-up research should examine the productivity of uphill forwarding operations on a variety of sites.

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Sažetak

Proizvodnost izvoženja drva u južnoj Austriji

Forvarderi se uobičajeno koriste pri sortimentnoj metodi izradbe drva. U Austriji se 17 % izrađenih drvnih sortimenata izvozi forvarderima. Mnogi čimbenici utječu na proizvodnost forvardera: vrsta drvnih sortimenata, obujam tovara, udaljenost izvoženja, sječna gustoća. Stoga su potrebna istraživanja proizvodnosti i troškova sustava izvoženja drva koja bi bila upotrebljiva pri planiranju i organizaciji radova.

Istraživanje je provedeno na dvije sječine na osnovi studija vremena pri radu dvaju različitih tipova strojeva: forvardera i harvardera. Cilj je istraživanja razvoj modela proizvodnosti i troškova izvoženja drva s obzirom na utjecajne čimbenike.

Na prvoj je sječini korišten harvarder Ponsse Buffalo Dual pri sječi stabala i izvoženju drvnih sortimenata iz mješovitih sastojina smreke, jele, ariša i bora. Na drugoj je sječini korišten forvarder Gremo 950R za izvoženje drvnih sortimenta, dok se za sječu i izradu koristio harvester. Osnovne su značajke sječina prikazane u tablici 1, a *šumskih vozila u tablicama 2 i 3. Prosječni je nagib terena na prvoj sječini iznosio 11 %, a na drugoj 39 %. Pri radu na strmom terenu forvarder je bio opremljen vitlom te se kretao od pomoćnoga stovarišta do mjesta utovara u smjeru uzdužnoga nagiba terena namatanjem užeta koje je bilo vezano na dubeće stablo.*

Ukupno su snimljena 82 radna turnusa protočnom metodom studija vremena. Radni turnus forvardera uključuje neopterećeno kretanje vozila, utovar drva, opterećeno kretanje vozila te istovar drva. Prekidi su rada zabilježeni u svakom turnusu. Također su mjereni utjecajni čimbenici izvoženja drva: udaljenost izvoženja, obujam tovara, obujam pojedinoga drvnoga sortimenta te nagib traktorske vlake.

Ostvarena je prosječna proizvodnost iznosila 17,9 m^3 po pogonskom satu rada. Opterećeno se kretanje vozila odvijalo niz nagib te su ostvarene veće brzine kretanja nego pri neopterećenom kretanju vozila. Prosječni je jedinični trošak izvoženja drva iznosio 6,72 EUR/m^3.

Linearnom multivarjantnom su se regresijom odredile statistički značajne varijable (udaljenost izvoženja, obujam komada, tip forvardera i nagib terena) te iskazao model utroška vremena pri izvoženju drva. U modelu varijabla F iznosi 1 za Ponsse Buffalo Dual harvarder, odnosno 0 za Gremo 950R forvarder.

Utjecaj pojedinih čimbenika na utrošak vremena izvoženja drva prikazan je na slikama 2, 3, 4 i 5 u opsegu izmjerenih vrijednosti. Slika 6 prikazuje postotni udio utroška vremena pojedine sastavnice radnoga turnusa, a tablica 6 zbirne statističke podatke mjerenih vrijednosti.

Rezultati istraživanja pokazuju da se povećanjem udaljenosti izvoženja povećava utrošak vremena rada forvardera. Utrošak se vremena izvoženja drva forvarderima smanjuje s povećanjem obujma komada te povećenjem nagiba vlake pri izvoženju drva nizbrdo. Daljnjim je istraživanjima potrebno odrediti proizvodnost forvardera pri izvoženju drva uz nagib pri različitim uvjetima rada.

Ključne riječi: *forvarder, proizvodnost, trošak, model, regresija*

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