Original scietific paper – *Izvorni znanstveni rad*

Roadside Chipping in a First Thinning Operation for Radiata Pine in South Australia

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Abstract – Nacrtak

Roadside chipping is a common harvesting system to produce chips in Australian plantations. This study investigated the productivity and cost of road-side chipping operation (chipping logs extracted by forwarder to the road side) using a Morbark chipper with flail delimber in a first thinning of Pinus radiata stands. An elemental time study method was used to collect the time working cycles. The regression approach was used to develop the productivity predicting model based on the log size in different wood piles. The statistical analysis yielded an average productivity of 59.4 GMt/PMH$_0$ with the corresponding costs of 5.2 AU$/GMt for the Morbark chipper. The details on work time analysis, relocation time and fuel consumption of the machine are documented in this paper. The results provide basic information for planning roadside chipping operations in pine plantations.

Keywords: Morbark chipper, Loader, Truck, Work time, Productivity, Cost, Model

1. Introduction – *Uvod*

Chipping can be done at the mill, at a storage yard, at forest roadside or in the stand (Kühmaier et al. 2007). The most common option for many regions is chipping at the forest roadside. About 70% of the annual woody biomass production in Finland is chipped at roadside (Ranta and Rinne 2006; Junginger et al. 2005). Road side chipping is the most common due to the cost benefits (Ghaffariyan 2010). Spinelli et al. (2009, 2002) reported that the full-tree harvesting system with roadside chipping allows lower cost harvesting and transport than the CTL system for a range of conditions.

Roadside chipping is also common in Australian plantations and utilises a mobile chipper to produce pulp chips in the forest. Road side chipping is preferred to the other harvesting systems due to minimizing materials processing (Lambert 2006). Stems must be debarked to produce quality pulp chips. Debarking for roadside chipping in Australia can be performed either by debarking the stems at the stump using a single-grip harvester, or alternatively, by debarking the stems with a chain flail delimber and debarker at the forest road prior to chipping. The flail and chipper are often integrated in one machine as in the Peterson Pacific flail chipper. The system of roadside chipping with debarking at the stump was developed by Eumeralla Pty Ltd and AFM Pacific in Australia in 1998, for Timbercorp Limited (Lambert 2006). The system of roadside chipping with debarking at the forest road is currently used in the Green Triangle Region, Albany and Bunbury in Australia.

Two recent studies on roadside chipping in Western Australia have reported productivity of 33.90 GMt/PMH$_0$ for the Peterson Pacific chipper (Wiedemann and Ghaffariyan 2010) and 51.7 GMt/PMH$_0$ for the Husky precision chipper (Ghaffariyan et al. 2011) in Eucalypt plantations. The difference between productivity of both studies was due to tree size and machine power. Larger tree size and machine power resulted in higher productivity (Spinelli and Hartsough 2001). Both studies indicated that truck waiting time was the major operational delay.

Since the productivity and cost of chipping logs at roadside have not been documented in Australian pine plantations, this project investigated the productivity of roadside chipping operation in a first thinning of *Pinus radiata*. The objectives of this trial were to:

- ⇒ Determine the productivity and cost of roadside chipping operation,
- ⇒ Study the impact of log size on chipper productivity,
- ⇒ Determine the fuel consumption of the chipping system.

2. Study area and harvesting system – *Mjesto istraživanja i sustav pridobivanja*

The study area was a flat 19.7 ha pine plantation with an original stocking of 1561 stems per ha and an average tree size of 0.12 m^3 near Mt Gambier, South Australia. The thinning system was performed by a cut-to-length (CTL) harvest system consisting of a harvester and forwarder, producing logs at roadside that were chipped by a Morbark B12 truck-based chipper (500 hp) directly into trailers for transport. The chipper was equipped with the debarking flail. A Hitachi ZAXIS 250L loader was used to feed the chipper (Fig. 1). The same operator was used for loader and chipper. Four B-double trucks (Fig. 2) were used for transport. The logs were chipped straight into the trailer. The chips were transported to the Carter Holt Harvey MDF mill in Mt Gambier. The transportation distance varied from 22.0 to 27.5 km.

3. Method – *Metoda*

The study took place in September 2011. Elemental time study method was used to evaluate the machine productivity for chipping 7 piles. Element level measurement consists of splitting the work cycle into functional steps (elements) and then recording time consumption separately for each of them. This allows the work process to be described in more detail, which may contribute to a better understanding of process dynamics (Magagnotti and Spinelli 2012). In this case study, the working cycle was defined as the time required for loading each truck. The working cycle in this project was divided to six working elements (Table 2). Working delays (including personal, mechanical and operational delays) during the operation were also recorded by stopwatch (Table 3). The collected data at each pile consisted of work cycles per pile, average log diameter, and standard deviation of log diameter measurements within each pile (Table 4). The product output (chip weight) was determined based on the delivered green metric tons (GMt) of chips (from truck weights).

Fig. 1 Hitachi loader – Morbark chipper
Slika 1. *Utovarivač Hitachi – Iverač Morbark*

Fig. 2 Morbark chipper and chip van
Slika 2. *Iverač Morbark i kamion za prijevoz drvne sječke*

Table 1 Harvesting machines used at study site
Tablica 1. *Strojevi za proizvodnju drvne sječke korišteni tijekom istraživanja*

Type *Tip stroja*	Make *Proizvođač*	Model *Model*	Hours used *Pogonskih sati*	Operator experience, years *Iskustvo rukovatelja, god.*
Tracked base loader *Gusjenični utovarivač*	Hitachi	ZAXIS 250L	3000	7
Chipper *Iverač*	Morbark	B12	4000	7

Table 2 Definition of working elements
Tablica 2. *Definicije radnih sastavnica*

Work element *Radna sastavnica*	Definition *Definicija*
Truck move to chipping place *Pomicanje kamiona do mjesta iveranja*	Starts when truck moves to chipper and ends when chipping is started – *Počinje kada se kamion pomiče prema iveraču, a završava s početkom iveranja*
Chipping *Iveranje*	Starts when operator starts picking up the logs and feeding into chipper and ends when trailer is full and truck commences travelling – *Počinje kada rukovatelj zahvati oblovinu i stavlja ju u iverač, a završava kada je prikolica puna i kamion se počinje kretati*
Moving chipper *Premještanje iverača*	Any time spent to move the chipper along the pile – *Svako vrijeme utošeno za pomicanje iverača uz složaj*
Debris clean up by loader *Uklanjanje ostataka utovarivačem*	Any time spent by the operator to pick up the debris and clean up the chipping area – *Svako vrijeme koje rukovatelj utroši za podizanje ostataka drvne sječke i čišćenje mjesta iveranja*
Planned fueling and knife change *Planirano točenje goriva i promjena noževa*	Any time to fuel the loader/chipper and change the knives of the chipper – *Svako vrijeme utrošeno za točenje goriva u utovarivač i iverač i za promjenu noževa iverača*
Relocate to next pile *Premještanje do sljedećega složaja*	Starts when chipper/loader starts moving to new pile in another place and ends when first truck starts moving into location to be loaded – *Počinje kada se iverač i utovarivač počinju kretati do novoga složaja na drugom mjestu i završava kada se prvi kamion počinje kretati na mjesto utovara*

Table 3 Working delay
Tablica 3. *Zastoj rada*

Delay – *Zastoj*	Definition – *Definicija*
Delay / Non-productive time *Zastoj / Neproizvodno vrijeme*	Any interruption to previous elements (note cause of delay: operational, personal or mechanical) *Svaki prekid prethodnih sastavnica (zabilježen razlog zastoja: organizacijski, osobni ili mehanički)* Delay will be treated as follows: – *Prekid će biti tretirani:* Delays <0.1 minute (6 seconds) are included in the element in which they occur as the time interruption is considered too short to constitute a delay – *Zastoji < 0,1 minute (6 sekundi) uključeni su u sastavnicu u kojoj su nastali jer se prekid rada smatra prekratkim da bi činio zastoj* Delays <15 minutes are recorded as delays and included in productive time – *Zastoji <15 minuta zabilježeni su kao zastoji i uključeni u proizvodno vrijeme* Delays >15 minutes are considered non-productive time and excluded – *Zastoji >15 minuta smatraju se neproizvodnim vremenom i isključeni su*

Table 4 Study lay-out and data collected at each pile
Tablica 4. *Dizajn istraživanja i podaci prikupljeni po pojedinom složaju*

Pile number *Redni broj složaja*	Collected work cycles *Broj snimljenih radnih ciklusa*	Average log diameter, cm *Prosječni promjer oblovine,* cm	Standard deviation for log diameter, cm *Standardna devijacija promjera,* cm
1	14	18.2	5.5
2	6	16.4	5.1
3	21	17.1	5.2
4	13	17.5	5.5
5	17	13.8	3.1
6	4	13.4	4.3
7	7	14.0	4.3

The log diameter (at one end) was measured using sampling of 85 logs per pile. The pile length was divided to five sections. In each section, the log end diameter were randomly measured at three heights including bottom, middle and top to sample the logs from all places in the pile at both sides (front and back side of the pile to roadside). For each pile the average log diameter was calculated using the recorded samples. According to the analysis of variance using Tukey method, the average diameter of the piles 1, 2, 3 and 4 was not significantly different of each other but it was different from piles 5, 6 and 7. For the other piles, the average diameter of the piles 5, 6 and 7 were not significantly different.

The lengths of logs averaged 5 m based on the measurement records of 30 logs at the end of each pile. The average log volume was 0.103 m^3, which was calculated based on Huber's formula by multiplying the log length with the average sectional area of a log at its mid-point. In this trial, the average height and length of the piles was 4 m and 66 m, respectively. The distance between piles averaged 199 m (minimum distance of 20 m and maximum distance of 440 m).

3.1 Statistical analysis – *Statistička analiza*

3.1.1 Modelling – *Modeliranje*

The working time and productivity were plotted depending on the average log diameter for the pile. The productivity model was developed using the regression method in SPSS 18. The statistical procedure for modeling included:

⇒ plotting the working time depending on the parameter,

⇒ regression application to develop the model (considering outliers outside three standard deviations),

⇒ comparing different model types based on fit, error and plausibility,

⇒ checking model consistency,

⇒ analyzing the variance to test significance of the model,

⇒ examining the residuals of the model and model evaluation,

⇒ sensitivity analysis to quantify the impact of the independent variable on chipper productivity.

3.1.2 Productivity – *Proizvodnost*

Productivity was calculated from the delivered green metric tonnes (GMt) of chips (from truck weights) with the productive machine hours excluding all delays (PMH_0) and productive machine hours excluding delays longer than 15 minutes (PMH_{15}).

The fuel consumption of the loader and chipper was also recorded during the operation to estimate the consumption per produced unit of chips.

4. Results – *Rezultati*

4.1 Productivity model – *Model za izračun proizvodnosti*

Average productivity of the chipper was 59.4 GMt/PMH_0 (56.6 GMt/PMH_{15}). The confidence interval for the mean net productivity is 59.20±2.29 GMt/PMH_0 at the significance level of 0.05. A model was developed to predict chipping productivity.

Productivity (GMt/PHM_0) = 18.79 + 2.505 × Average log end diameter of each pile, cm

$R^2 = 19.2\%$, $n = 79$, $df = 1{,}76$, $F = 18.07$, $p = 0.00059$

4.2 Model evaluation – *Ocjena modela*

From the collected work cycles, three samples were randomly taken out from the data and the model was developed without these witness samples. Then to verify the validity of the model, the confidence intervals of the coefficients were calculated in SPSS for the linear model (Table 5).

Table 5 Confidence intervals for coefficients of the model
Tablica 5. *Intervali pouzdanosti za koeficijente modela*

Model *Model*	Unstandardized Coefficients *Nestandardizirani koeficijenti*		95.0% Confidence Interval for B *95,0 %-tni interval pouzdanosti za B*	
	B	Std. Error *Standardna pogreška*	Lower Bound *Donja granica*	Upper Bound *Gornja granica*
Constant – *Konstanta*	18.79	9.56	–0.26	37.84
Log diameter – *Promjer oblovine,* cm	2.50	0.59	1.33	3.68

Table 6 Random witness samples and validation test
Tablica 6. *Slučajni uzorci izostavljeni iz regresije i provjera valjanosti*

Diameter, cm *Promjer*, cm	Log length, m *Duljina oblovine,* m	Pay load, t *Masa tovara,* t	Chipping time, min/cycle Vrijeme iveranja, min/*turnus*	Productivity, GMt/PMH_0 *Proizvodnost*, GMt/PMH_0			
				Actual *Stvarna*	Upper limit *Gornja granica*	Lower limit *Donja granica*	Predicted *Predviđena*
16.40	5.41	25.50	19.45	42.3	98.2	21.6	59.9
17.10	4.95	25.22	22.41	42.9	100.8	22.5	61.6
13.80	4.60	25.72	27.09	57.0	88.6	18.1	53.4

Table 7 Descriptive statistics of productivity model at $\alpha = 0.05$
Tablica 7. *Opisna statistika modela za izračun proizvodnosti za* $\alpha = 0,05$

	N	Minimum *Najmanja vrijednost*	Maximum *Najveća vrijednost*	Mean *Aritmetička sredina*	Std. Deviation *Standardna devijacija*
Net productivity, GMt/PMH_0 *Efektivna proizvodnost,* GMt/PMH_0	78	35.30	82.90	59.40	10.34
Log diameter, cm *Promjer oblovine,* cm	78	13.40	18.20	16.13	1.81

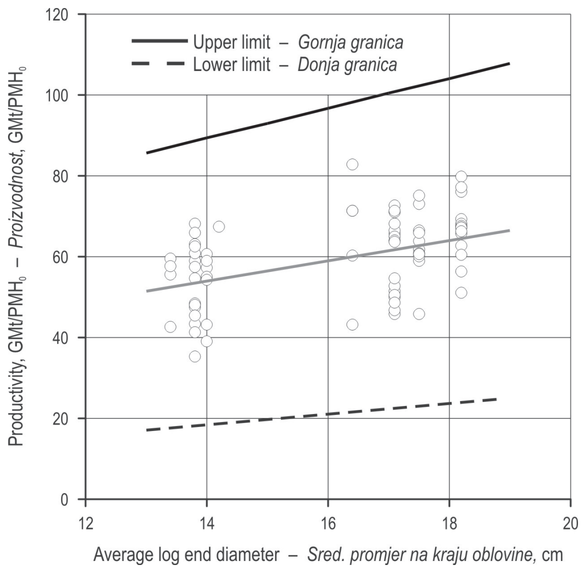

Fig. 3 Impact of log diameter on chipping productivity (for average log length of 5 m). Data points are actual observations. Solid line is a straight line created by varying log diameter in the productivity model. Upper and lower confidence limits of the prediction are presented

Slika 3. *Utjecaj promjera oblovine na proizvodnost iveranja (za prosječnu duljinu komada oblovine od 5 m). Točke na grafu stvarna su opažanja. Puna je linija nacrtana variranjem promjera oblovine u modelu za izračun proizvodnosti. Prikazane su gornja i donja granica pouzdanosti procjene*

The upper limit and lower limit for prediction for each witness sample are calculated at $\alpha = 0.05$ (Table 6). Since each observed productivity is within the limits, the model is considered to be valid at $\alpha = 0.05$.

The actual productivity of each witness sample (Table 6) was also compared with the predicted productivity by the developed model using the Paired Samples *T* Test (Spinelli and Magagnotti 2010). The significance level of this test was 0.272, which was higher than $\alpha = 0.05$. This indicated that there was no significant difference between the actual and predicted values.

Mean productivity is 59.40 GMt/PMH_0 at the mean log diameter of 16.13 cm (Table 7). The minimum and maximum value of net productivity and log diameter among the recorded cycle times of the chipper in this case study is included in Table 7.

Chipping larger diameter logs of the same length will increase chipping productivity and reduce the time to fill each trailer (Fig. 3).

4.3 Work element times – *Vrijeme radnih sastavnica*

The operator spent most of the working time (83.99%) chipping (Fig. 4). The working delays were grouped into three categories; personal, mechanical and operational delays. The major operational delay

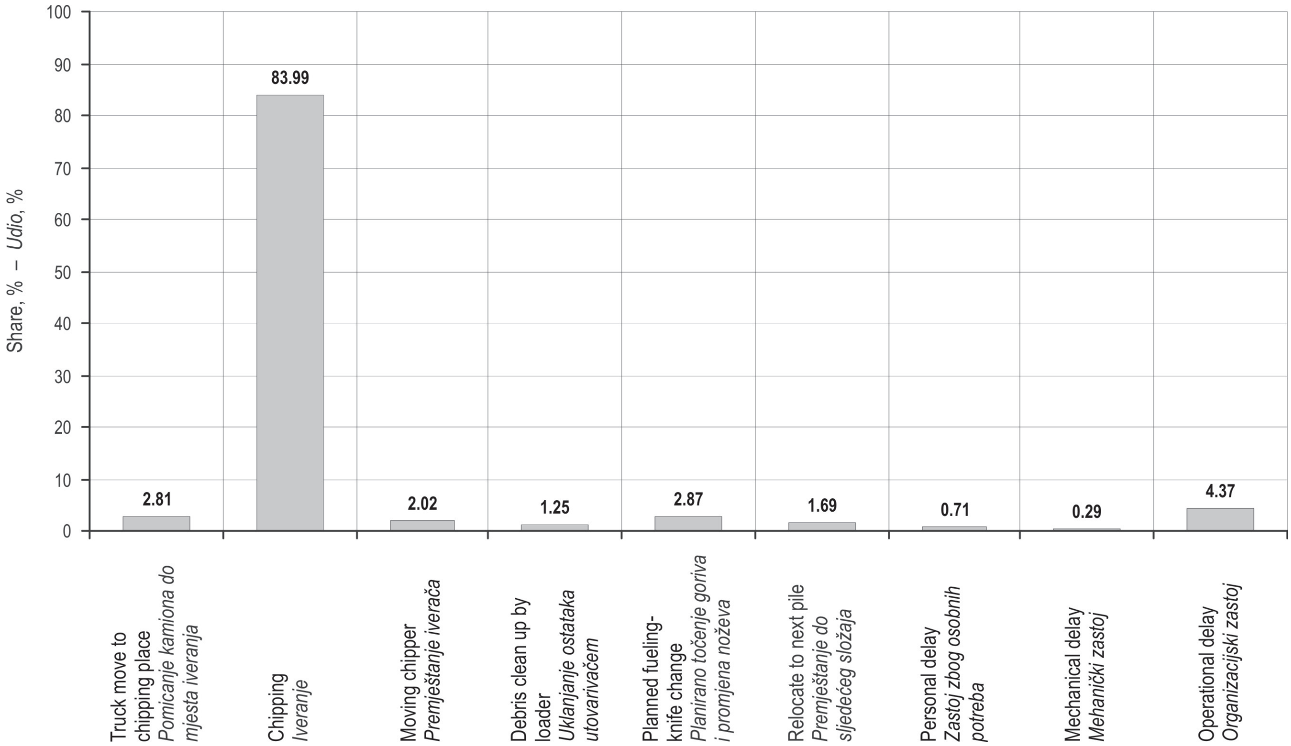

Fig. 4 Time breakdown (% of working time) for chipper
***Slika 4.** Raščlamba vremena (u % od radnoga vremena) za iverač*

Table 8 Minimum, Maximum and Average values for the work element times
***Tablica 8.** Najmanje, najveće i prosječne vrijednosti za utrošak vremena pojedinih radnih sastavnica*

Work element, minutes *Radna sastavnica,* minute	Minimum *Najmanja vrijednost*	Maximum *Najveća vrijednost*	Mean *Aritmetička sredina*
Truck move to chipping place – *Pomicanje kamiona do mjesta iveranja*	0.0	23.1	0.8
Chipping – *Iveranje*	16.9	33.0	23.2
Move chipper – *Premještanje iverača*	0.5	4.9	1.5
Debris clean up by loader – *Uklanjanje ostataka utovarivačem*	0.4	5.1	1.7
Planned fuelling-knife change – *Planirano točenje goriva i promjena noževa*	6.4	15.6	10.7
Relocate to next pile – *Premještanje do sljedećega složaja*	4.5	16.2	9.4
Personal delay – *Zastoj zbog osobnih potreba*	0.1	5.5	2.3
Mechanical delay – *Mehanički zastoj*	6.6	6.6	6.6
Operational delay – *Organizacijski zastoj*	2.0	16.6	8.1

(4.37% of working time) occurred when the chipper was waiting for a truck. The mechanical delay occurred due to breakage in the loader grapple. The total work time observed (including delays) was about 2232.8 minutes in this case study.

The average work cycle time was about 27.2 minutes including delays shorter than 15 minutes. Minimum and maximum values for the work cycle time (including delays shorter than 15 minutes) were 17.3 and 43.5 minutes, respectively. The descriptive statistics of

Table 9 Time records for the major move of chipper-loader
Tablica 9. *Evidentirani utrošci vremena za glavno premještanje iverača i utovarivača*

	Time, min. – *Vrijeme*, min.
1. Relocate chipper – *Premještanje iverača*	21.15
2. Relocate excavator – *Premještanje utovarivača*	117.29
2.1 Wait for truck for relocating – *Čekanje na kamion koji će prevesti utovarivač*	74.40
2.2 Loading into truck – *Utovar utovarivača*	18.34
2.3 Travel to next pile – *Vožnja do sljedećega složaja*	20.00
2.4 Unloading excavator from truck – *Istovar utovarivača*	4.55

the work element times recorded in this case study are presented in Table 8.

In this case study, the average payload of the trucks was about 24.7 GMt (with the minimum and maximum of 22.7 GMt to 26.9 GMt, respectively).

4.4 Major relocation – *Glavno premještanje*

After completing the last pile in this study, the chipper and loader were moved to another forest area. The chipper was truck-based and moved itself to the new location, whereas the excavator-based loader was moved using a float (lowboy) causing a much longer delay. The total time for the major move was 1.95 hours for a distance of 10.4 km (Table 9).

4.5 Fuel consumption – *Utrošak goriva*

The fuel consumption for the chipper averaged 72.6 l/PMH_{15} and the loader consumed 25.1 l/PMH_{15}. As the loader only worked while the chipper was operating (except for some very short exceptions), the total consumption was about 97.7 l/PMH_{15} (1.72 l/GMt) or about 65.4 MJ/GMt. The fuel cost for the chipper and loader is estimated to about 122.0 A$/$PMH_{15}$.

4.6 Cost of operation – *Trošak iveranja*

The machine hourly cost was calculated based on operating, fixed and labour cost (Table 10, 11) using ALPACA: Australian Logging Productivity and Cost Appraisal Model (Murphy and Acuna 2009). The main inputs for cost estimating using ALPACA include equipment purchase price, machine life, salvage value, utilization rate, repair and maintenance, fuel consumption, operator wage and scheduled machine hours.

Increasing log diameter reduced chipping cost (Fig. 5) as the larger log diameter resulted in higher productivity of the chipper.

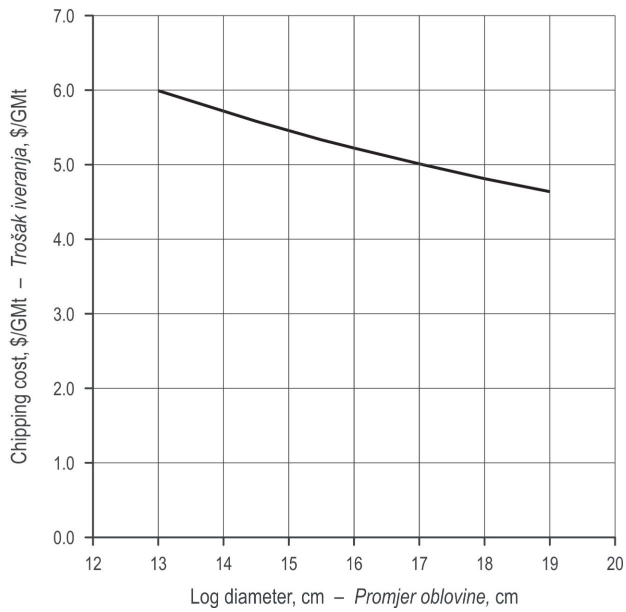

Fig. 5 Impact of log diameter on chipping cost
Slika 5. *Utjecaj promjera oblovine na trošak iveranja*

5. Discussion – *Rasprava*

Using a separate loader with the Morbark chipper is one of the reasons for the high cost in this case study compared to European chippers (Stampfer and Kanzian 2009). The result of the productivity model is similar to the chipping productivity in Italy, where 85% of total working time was spent chipping and the productivity of chipper was a function of piece size and machine power (Spinelli and Hartsough 2001; Spinelli et al. 2011). However, the average productivity for their study was about 13.2 GMt/PMH_0 due to smaller piece size of 0.07 m^3 and lower power of the chipper. Spinelli and Maganotti (2010) developed a productivity-cost estimation tool that included the en-

Table 10 Machine cost calculations (based on Australian Dollar AU$)
Tablica 10. *Izračun troška strojnoga rada (iskazana u australskim dolarima AU$)*

Machine description/costs – *Značajke stroja i troškovi*	Morbark B12	Hitachi ZAXIS 250L
Purchase price, $ – *Nabavna vrijednost,* $	375000	228800
Machine life, years – *Uporabni vijek stroja,* godine	7.0	5.0
Salvage value, % – *Ostatak vrijednosti,* %	20	20
Utilization rate, % – *Iskorištenost,* %	75	75
Repair and maintenance, percent of depreciation, % – *Popravci i održavanje, postotak od amortizacije,* %	100	100
Interest rate, % – *Kamatna stopa,* %	7	7
Insurance and tax rate, % – *Stopa osiguranja i poreza,* %	4	4
Fuel consumption rate, l/h – *Potrošnja goriva,* l/h	72.6	25
Fuel cost, $/l – *Cijena goriva,* $/l	1.25	1.25
Lube and oil, percent of fuel cost, % – *Mazivo i ulje, postotak od troška goriva,* %	25	25
Operator wage and benefit rate, $/SH – *Plaća i doprinosi rukovatelja,* $/SMH	25.20	0.00
Scheduled machine hours, h – *Planirani radni sati,* h	2200	2500
Salvage value, $ – *Ostatak vrijednost,* $	75000	45760
Annual depreciation, $ – *Godišnja amortizacija,* $	42857	36608
Average yearly investment, $ – *Prosječna godišnja investicija,* $	246429	155584
Productive Machine Hours, PMH – *Pogonskih sati godišnje,* PMH	1650	1875
Ownership costs – *Troškovi posjedovanja stroja*		
Interest cost, $/year – *Trošak kamata,* $/godina	17250	10891
Insurance and tax cost, $/year – *Trošak osiguranja i poreza,* $/godina	9857	6223
Yearly ownership cost, $/year – *Godišnji trošak posjedovanja stroja,* $/godina	69964	53722
Ownership cost per SMH, $ – *Trošak posjedovanja stroja po planiranom radnom satu,* $	31.80	21.49
Ownership cost per PMH, $ – *Trošak posjedovanja stroja po pogonskom satu,* $	42.40	28.65
Operating costs – *Troškovi korištenja stroja*		
Fuel cost, $/h – *Trošak goriva,* $/h	90.70	31.36
Lube cost, $/h – *Trošak maziva,* $/h	22.67	7.84
Repair and maintenance cost, $/PMH – *Trošak popravaka i održavanja,* $/PMH	25.97	19.52
Operator labor and benefit cost, $/PMH – *Trošak rada rukovatelja i doprinosi,* $/PMH	33.60	0.00
Supervision, $/PMH – *Nadzor,* $/PMH	5.04	0.00
Operating cost per PMH, $/PMH – *Trošak posjedovanja stroja po pogonskom satu,* $/PMH	177.99	58.72
Operating cost per SMH, $/SMH – *Trošak posjedovanja stroja po planiranom radnom satu,* $/SMH	133.49	44.04
Total Costs – *Ukupni troškovi*		
Total cost per SMH, $/SMH – *Ukupni trošak po planiranom radnom satu,* $/SMH	165.29	65.53
Total cost per PMH, $/PMH – *Ukupni trošak po pogonskom satu,* $/PMH	220.39	87.37

Table 11 Summary of cost-production of the chipping system
Tablica 11. *Rekapitulacija troška proizvodnje sustavom iveranja*

Chipper cost, AU$/PMH *Trošak iverača,* AU$/PMH	Loader cost, AU$/PMH *Trošak utovarivača,* AU$/PMH	System cost, AU$/PMH *Trošak sustava,* AU$/PMH	Productivity, GMt/PMH_0 *Proizvodnost,* GMt/PMH_0	AU$/GMt
220.39	87.37	307.76	59.40	5.18

gine power and piece size. Based on their results, larger piece size resulted in higher chipping productivity, which is similar to our study result (chipping productivity model, Fig. 3).

The productivity of the Morbark chipper in our case study is higher than the reported productivity of 8.12 GMt per scheduled hours (SH) for a Morbark Super Beaver Chipper (with integrated feeding loader) used to chip Eucalypt trees into trailers near Orland, California, USA. This low productivity was caused by small tree *DBH* of 7.5 cm in the California case study (Hartsough and Nakamura 1990). Watson et al. (1986) tested two types of Morbark chipper (Models 27 and 20) to chip the trees for bioenergy purposes in pine and hardwood plantations in Alabama, USA. The average productivity for chipping pine trees at *DBH* of 7.5 cm for Model 27 (650 hp) and Model 20 (350 hp) was 49.10 and 27.70 GMt/PMH, respectively. *DBH* was found to be a significant variable for the chipping productivity predicting model. Compared to our study, the Morbark 27 is more productive than the Morbark B12 due to its higher engine power. However, for the same *DBH* (about 18 cm), the Morbark 20 model in Alabama recorded a productivity of 37.0 GMt/PMH (average moisture content of 52.9%), which is lower than our case study results due to difference in engine power. In another study in loblolly pine (*Pinus taeda*) in Louisiana (USA), the productivity for chipping bundles of stems (with *DBH* from 7.5 cm to 22.5 cm) by Peterson 5000 flail-chipper was about 13.5 GMt/PMH (Watson and Stokes 1994). Stokes and Watson (1990) mentioned that using flail delimbing and debarking allows economical processing and chipping to produce clean and acceptable chips in slash pine (*Pinus elliotti*) plantations in southern United States. In their case study the Peterson Pacific 4800 log debarker was combined with the Morbark 22 chipper for chipping pine logs, while the Morbark B12 in our case study was integrated with a flail debarker.

Waiting for trucks is the typical operational delay with roadside chipping. This has been previously investigated in Quindinup, Western Australia (Ghaffariyan et al. 2011). For whole tree chipping in Western Australia, 13% of total chipping time was delay due to waiting for trucks, which is higher than the current case study. Three trucks worked with one Husky Precision chipper in that case study. In this trial four trucks transported the chips produced by the Morbark chipper. Spinelli and Visser (2009) investigated the working delay of 63 chipping productivity studies. The overall average utilization of the chipper was 73.8%. Regardless of operation type, two-thirds of the total delay time was represented by organizational delays, which emphasizes the crucial role of operation management. The percentage of operational delay was also larger than other work delays in our case study. However, its percentage was less than average delay of 63 case studies analyzed by Spinelli and Visser (2009).

6. Conclusions – *Zaključci*

Increasing the diameter of the logs for the same length, and up to the maximum diameter accepted by the machine will increase the productivity of the chipping operation. This is probably only true when comparing diameter differences of more than 3 or 4 cm. Future studies can investigate the chipping productivity model for larger tree sizes in a second thinning and final cuts. To decrease the cost of operation, a chipper with loader attachment (O'Neal and Gallagher 2007) can be also tested. Using a separate loader increases hourly cost based on the assumptions for the whole crew although ergonomically it is better for the operator to be far from vibrations and noise. Another possibility will be the application of a smaller loader for small pulp logs with a lower hourly cost to feed the chipper.

The most delay time derived from chipping occurred due to waiting for trucks. Proper planning and management of the truck fleet is critical to infield chipper efficiency. Making sure there are enough trucks so that the system is not delayed has a cost too, which should be considered in chipping operation planning. A fairly simple operation like this can be managed manually, however, for more complex operations, truck scheduling systems like Fast Truck (Acuna et al. 2012), ASICAM (Weintraub et al. 1996), Asset Forestry

New Zealand transportation system (Robinson 2012) or Forestry Transportation Management System by Trimble (www.trimbleforestryautomation.com) could be used.

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Sažetak

Iveranje na pomoćnom stovarištu nakon prve prorede šumske kulture kalifornijskoga bora u Južnoj Australiji

Iveranje je na pomoćnom stovarištu uobičajen sustav proizvodnje drvne sječke u australskim šumskim plantažama. Ovom je studijom istražena proizvodnost i troškovi iverača Morbark pri iveranju oblovine (izvezene forvarderom na pomoćno stovarište) iz prve prorede šumske kulture kalifornijskoga bora. Pokus je proveden u borovoj šumskoj kulturi površine 19,7 ha koja je podignuta na ravnom terenu blizu grada Mount Gambier u Južnoj Australiji. Drvnu je zalihu činilo 1561 stablo po hektaru, prosječnoga obujma 0,12 m^3*. Proveden je studij vremena na razini radnoga ciklusa pri iveranju sedam složaja oblovine. Svaki je radni ciklus raščlanjen na šest radnih sastavnica: pomicanje kamiona do mjesta ivaranja, iveranje, premještanje iverača, uklanjanje ostataka utovarivačem, planirano točenje goriva i promjena noževa i premještanje do sljedećega složaja.*

Model za izračun proizvodnosti iveranja razvijen je pomoću regresije na temelju veličine komada oblovine u različitim složajevima iskazane promjerom. Ocjena je modela obavljena pomoću tri slučajna uzorka izostavljena iz regresije. Testiranje je potvrdilo da je model valjan za razinu pouzdanosti 0,05. Statistička je analiza rezultirala prosječnom proizvodnošću od 59,4 GMt/PMH_0 *i odnosnim troškovima u iznosu 5,2 AU$/GMt. Povećanje promjera oblovine dalo je veću proizvodnost iverača i niži trošak iveranja. Rukovatelj je većinu radnoga vremena (83,99 %) utrošio na iveranje. Zastoji u radu objedinjeni su u tri kategorije: osobne, mehaničke i organizacijske. Glavni organizacijski zastoj (4,37 % radnoga vremena) nastao je prilikom čekanja kamiona. Ukupno vrijeme utrošeno za glavno premještanje na udaljenost od 10,4 km iznosilo je 1,95 h. Prosječni je utrošak goriva iznosio 72,6 l/*PMH_{15} *za iverač i 25,1 l/*PMH_{15} *za utovarivač.*

Rezultati ovoga istraživanja pružaju osnovne informacije za planiranje iveranja na pomoćnom stovarištu u borovim šumskim kulturama.

Ključne riječi: iverač Morbark, utovarivač, kamion, radno vrijeme, proizvodnost, trošak, model

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