Evaluating Efficiency, Chip Quality and Harvesting Residues of a Chipping Operation with Flail and Chipper in Western Australia

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Abstract – Nacrtak

Roadside chipping is a common harvesting system in Australian plantations, which utilizes a mobile chipper stationed at the field edge to produce high-quality pulp chips for export. The studied harvesting system included a feller-buncher, two grapple skidders, a flail-debarker and a disc chipper. The study goals were to determine machine productivity, operation costs, fuel consumption, chip quality and measure the amount of slash left in the field after harvesting. The average productivity for feller buncher and skidder were about 97.26 GMt/PMH$_0$ and 60.22 GMt/PMH$_0$, respectively. The productivity of flail and chipper averaged at 57.80 GMt/PMH$_0$ and 58.18 GMt/PMH$_0$ in this case study. The transportation productivity averaged about 57.34 GMt/PMH$_0$. Time studies and regression analysis were used to model machine productivity. Tree size had significant impact on the feller-buncher productivity, while skidding distance was a significant variable affecting skidding productivity. Operation costs were evaluated using the ALPACA (Australian logging productivity and cost appraisal) model. This paper offers valuable information about the impact of different factors on feller-buncher and skidder productivity. Application of two skidders resulted in high total operating cost. Extracting whole trees to roadside yielded a very small amount of remaining slash distributed on the site.

Keywords: whole tree harvesting, feller-buncher, skidder, flail-debarker, cost, slash

1. Introduction – *Uvod*

The most common option in the production of woody biomass is chipping in the forest at roadside followed by transportation of the chips (Stampfer and Kanzian 2006). In Denmark in-field chipping is often used in thinning and small diameter tree harvesting (Talbot and Suadicani 2005). About 75–80 % of the annual woody biomass production in Sweden is produced in this way (Ranta and Rinne 2006, Junginger et al. 2005).

Roadside chipping is a common harvesting method in Australian eucalypt plantations. It utilizes a mobile chipper to produce export grade pulp chips at the plantation. If the fundamental objective of logistical efficiency is to handle the largest piece size the least number of times, roadside chipping must be considered as preferential to any other method. Chips production at the roadside 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 (Lambert 2006).

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. This system uses single grip harvesters to fell, delimb and debark full tree lengths at the stump and position them for subsequent extraction. From this point, a purpose built tree-length forwarder extracts

Table 1 Harvesting equipment for roadside chipping with Husky Precision
Tablica 1. *Oprema za pridobivanje drvne sječke strojevima Husky Precision*

Machine type *Tip stroja*	Make *Proizvođač*	Model *Model*	Power, kW *Snaga*, kW	Hours used *Pogonskih sati*	Operator experience, years *Iskustvo rukovatelja, god.*	Hourly machine cost, $ *Trošak strojnoga rada po satu*, $
Tracked swing-to-tree feller-buncher *Gusjenični feler bančer*	Tigercat	845C (shear head: Tigercat 2001)	191	4 738	4	240.59
Rubber tired grapple skidder *Kotačni skider s kliještima*	Tigercat	630C (S9)	184	3 811	0.3	278.84
Rubber tired grapple skidder *Kotačni skider s kliještima*	Tigercat	630D (S10)	191	748	0.7	203.07
Flail *Procesor za kresanje grana i koranje*	Husky Precision	FD 2300-4	309	3 993	2	345.68
Chipper *Iverač*	Husky Precision	HTC 2366	441	8 624	2.5	383.15

the stems to the forest road for stockpiling. Finally, the full-length, debarked trees are chipped using a chipper at the roadside.

The method of roadside chipping with debarking at the forest road is currently being used in the Green Triangle Region, Albany and Bunbury in Australia. In this system, trees are felled and bunched using a drive-to-tree feller-buncher. The felling can also be commonly carried out by a boom-mounted swing-to-tree feller-buncher, which has the ability to process multiple rows at a time and can place the bunches in the out-row with less machine movement. The feller-buncher head can be installed on a rubber-tired or a tracked based machine. At the roadside, trees are delimbed and debarked using a chain flail delimber/debarker and then chipped in the trailer. The delimber/debarker can be integrated with the chipper, such as the Peterson Pacific DDC5000 (DDC), or separate from the chipper, such as the combination of the Husky Precision Flail and Chipper (F/C). A number of different variations of these machines have been tested over the years (Lambert 2006).

Two recent studies on roadside chipping operations in Western Australia reported a productivity of 33.90 GMt/PMH_0 for the Peterson Pacific chipper (Wiedemann and Ghaffariyan 2010) and 51.70 GMt/PMH_0 for Husky precision chipper (Ghaffariyan et al. 2011). Both studies indicated that the major operational delay was the waiting time for trucks. This delay may be reduced through improved truck scheduling. The Husky Precision chipper study (Ghaffariyan et al. 2011) was about chipping small trees for biomass usage and no flail was used to debark the trees. The current study investigated the chipper and flail to produce pulp export chip, which is a common system in Western Australia. To add to the body of knowledge about the productivity of this harvesting method in Australia, this study aimed to investigate the efficiency of a road-side chipping system using a Husky Precision chipper.

The objectives of this study were to:

⇒ Measure productivity of each machine of the system,
⇒ Estimate the cost of each machine and of the whole system,
⇒ Study impact of different parameters on productivity,
⇒ Measure fuel consumption of each machine and of the whole system,
⇒ Measure harvesting residues retained on the site after logging operation,
⇒ Assess the quality of chips produced.

2. Materials and Methods – *Materijal i metode*

2.1 Study area – *Mjesto istraživanja*

The study area was located in a *Eucalyptus globulus* (Blue gum) plantation in southwest Western Australia, 58 km from the delivery point for all the products, the

Albany Plantation Export Company (APEC) chip mill. The study area was about 1.45 ha of flat terrain. The diameter at breast height over bark (DBHOB) and total tree volume averaged at 17.8 cm and 0.21 m^3. The stocking was 711 stems per ha.

Table 1 describes the machine used for the harvesting system. The trees were felled, bunched and skidded to the roadside as whole trees, then processed into pulp chips, and loaded directly into trucks for transport. The whole trees were processed by a Husky flail. The trees were delimbed and debarked using the flail. Then the debarked wood was fed into the chipper. The trucks used in this study were pocket road train type with the loading capacity of 60 tonnes. The chipping residues were returned to the site as »beehives« using the grapple skidders.

Table 2 Work elements for the feller-buncher, skidder and truck (Acuna and Heidersdorf 2008)

Tablica 2. *Definicije radnih elemenata feler bančera, skidera i kamiona (Acuna i Heidersdorf 2008)*

Machine *Stroj*	Work elements *Radni elementi*	Definition *Definicija*
Feller-buncher *Feler bančer*	Positioning *Zauzimanje položaja*	Any time spent for the movement of machine to place to start felling – *Svako vrijeme utrošeno za pomicanje stroja na mjesto početka sječe*
	Felling-bunching *Sječa i uhrpavanje*	Starts when felling head is attached to tree to start cutting. It finishes when operator lays the felled tree on the ground – *Počinje kada sječna glava obuhvati stablo i počinje sjeći. Završava kada rukovatelj položi posječeno stablo na tlo*
	Traveling *Premještanje*	Begins when the machine starts to travel to next tree and ends when the machine stops moving to perform some other activity – *Počinje kada se stroj krene premještati do sljedećega stabla, a završava kada se stroj prestane kretati i započinje obavljati neku drugu aktivnost*
	Clearing *Raščišćavanje*	Starts when the machine stops moving or felling/bunching to dispose of non-merchantable material and stops when feller/bunching or moving recommences – *Počinje kada se stroj prestane kretati ili sjeći i uhrpavati radi raščišćavanja nekomercijalnoga drvnoga amaterijala, a prestaje kada se sječa i uhrpavanje ili kretanje stroja nastavi*
Grapple skidder *Skider s kliještima*	Clear debris *Uklanjanje ostatka*	Any time spent for clearing debris and removal to stockpile or return to the block – *Svako vrijeme utrošeno za uklanjanje ostatka nakon iveranja i njegovo uhrpavanje ili vraćanje u sječinu*
	Travel empty *Vožnja praznoga*	Starts when machine commences travel into block and ends when loading of bunch commences – *Počinje kada stroj započinje vožnju u sječinu, a završava kada počinje utovarivati*
	Loading *Utovar*	Starts with grappling the bunch and picking up and ends when travel loaded commences – *Počinje sa zahvaćanjem i podizanjem tovara, a završava s početkom vožnje opterećenoga skidera*
	Travel loaded *Vožnja punoga*	Starts when wheels commence turning after loading, and ends when skid distance to the landing is reached *Počinje kada se kotači skidera počinju okretati nakon utovara, a završava kada se prevali udaljenost privlačenja do pomoćnoga stovarišta*
	Unloading *Istovar*	Time to drop load and turn around to commence travel empty. Starts when skid distance to deck is reached and ends when turn around is completed – *Vrijeme potrebno za istovar tovara i okretanje prije početka vožnje praznoga skidera. Počinje kada se prevali udaljenost privlačenja do mjesta istovara, a završava s okretanjem*
Truck *Kamion*	Loading *Utovar*	Begins when chipper starts blowing the chips into truck and ends when truck starts travelling loaded – *Počinje kada iverač započne upuhivati drvnu sječku u kamion, a završava kada puni kamion započinje vožnju*
	Travel loaded *Vožnja punoga*	Starts when loading finishes and truck starts travelling loaded to the mill and ends when unloading starts *Započinje sa završetkom utovara i početkom vožnje punoga kamiona u tvornicu, a završava s početkom istovara*
	Unloading *Istovar*	Starts when travel loaded ends at the mills and ends after being fully unloaded at the time of starting travelling empty – *Započinje sa završetkom vožnje punoga kamiona u tvornici, a završava nakon potpunoga istovara, u trenutku početka vožnje neopterećenoga kamiona*
	Travel empty *Vožnja praznoga*	Starts when truck driver commences to travel at the end of unloading element. It ends when loading starts *Počinje kada vozač kamiona započinje vožnju na kraju istovara. Završava s početkom utovara*

Table 3 Productivity, cost and fuel consumption of roadside chipping with Husky Precision
Tablica 3. *Proizvodnost, trošak i utrošak goriva pri iveranju na pomoćnom stovarištu strojevima Husky Precision*

Machine *Stroj*	Productivity, GMt/PMH$_0$ *Proizvodnost,* GMt/PMH0	Cost, $/GMt *Trošak,* $/GMt	Fuel consumption, l/hr *Utrošak goriva,* l/h	Fuel consumption, l/GMt *Utrošak goriva,* l/GMt
Feller-buncher *Feler bančer*	97.26	2.55	32.09	0.33
Grapple skidder (two skidders) *Skider s kliještima (dva skidera)*	60.22	12.02	91.91	1.58
Husky Precision flail *Procesor Husky Precision*	57.80	5.98	44.51	0.77
Husky Precision chipper *Iverač Husky Precision*	58.18	6.59	72.14	1.24
Truck *Kamion*	14.96	4.19	–	–
Total *Ukupno*	–	31.33	–	3.92

2.2 Method – *Metoda*

2.2.1 Time study and modeling – *Studij vremena i modeliranje*

The elemental time study method was used to evaluate machine productivity for the feller buncher, two grapple skidders and trucks. The felling-bunching and skidding working cycles were divided into the specific elements described in Table 2. Personal, mechanical and operational delays were also recorded during the time study. Productivity was calculated by the delivered tonnes of chips (GMt) and productive machine hours, excluding all delays (PMH$_0$). Backward stepwise regression was applied to develop the productivity predicting equations in SPSS 18. If any variable had significant impact on the residual mean square of the models, it was included in the models. The analysis of variance of each model was used to verify the significance of the model. The models were validated using witness samples, and the confidence intervals for each coefficient were calculated. By recording the total working time and delivered volume, the productivity of the flail, chipper and trucks were estimated.

2.2.2 Harvesting costs – *Troškovi pridobivanja*

The hourly machine cost included fixed, variable and labor costs. The hourly machine cost for each harvesting machine was modeled using the ALPACA (Australian Logging Productivity And Cost Appraisal) calculator, developed by Murphy and Acuna (2009). Unit cost was determined by dividing hourly machine cost by the net machine productivity.

2.2.3 Yield and chip quality – *Količina i kakvoća drvne sječke*

The yield was based on weighbridge data of the chips delivered to the mill. Using 8 samples of about 2 kg each, the moisture content of the chips was estimated to calculate the yield in bone dry metric tonnes (BDMt). The samples were tested for their size classification and bark content according to the APEC export chip specifications.

2.2.4 Assessment of harvest residues – *Procjena količine drvnoga ostatka*

There were two types of harvesting residues in this study; scattered residues left at the stump site and flail residues piled at roadside. The amount of stump site residues was estimated using two lines transects 20 m apart, along which 4 square plots of 1x1 m were established every 20 m. All the slash on each sample plot was collected manually and weighed with a portable scale. Roadside residues were taken back to the field with the skidder and stacked into piles, also called »beehives«. The »beehives« were evenly distributed over the site. The bulk volume of 6 samples of »beehives« was determined by measuring the length, width, height and cross-sectional shape of each pile. The total number of the »beehives« was about 66. By multiplying the average volume to the number of »beehives«, the total volume was estimated. No information on bulk density was available to convert the volume of »beehives« to weight.

3. Results – *Rezultati*

3.1 Productivity, cost and fuel consumption *Proizvodnost, trošak i utrošak goriva*

Table 3 shows the measured productivity, cost and fuel consumption for each machine engaged in the test operation. Skidding had the highest cost, and incurred the highest fuel consumption per GMt. The main reason for using two skidders was to avoid waiting time for the chipper while extracting the trees and clearing debris, which might take long time when using one skidder in the operation.

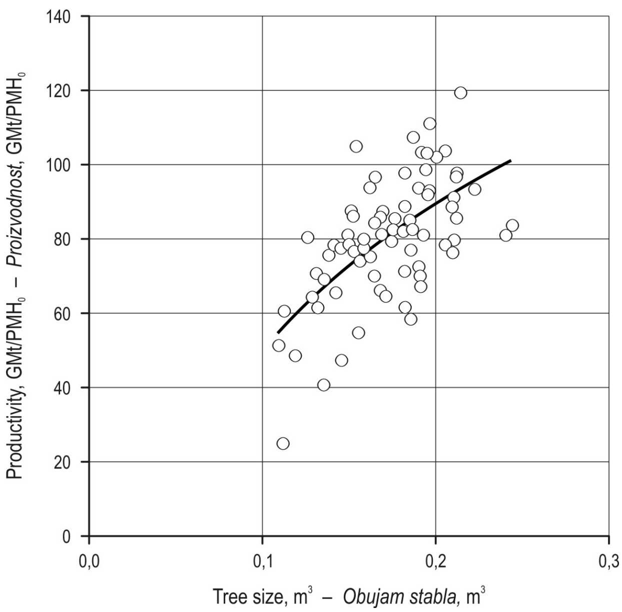

Fig. 1 Impact of tree size on feller-buncher productivity
Slika 1. *Utjecaj obujma stabla na proizvodnost feler bančera*

3.2 Feller-buncher productivity model – *Model za izračun proizvodnosti feler bančera*

Tree size significantly impacted the productivity of the feller-buncher. Increasing tree size resulted in higher productivity (Fig. 1). The model is significant at $\alpha = 0.05$ (Table 4). The model is:

$$\text{Productivity (GMt/PHM}_0) = 182.078 + 57.585 \times \ln(\text{Tree size (m}^{-3}))$$

$$R^2 = 40.2\%, n = 80$$

Table 5 summarizes the percent incidence of each work step on total time consumption, for the Tigercat feller-buncher. Felling and bunching accounted for over 95% of work time. No delay occurred for the duration of our time study.

3.3 Skidder productivity model – *Model za izračun proizvodnosti skidera*

Tree size did not have any significant impact on skidder productivity and therefore it was excluded from the model. Skidding distance significantly affected the productivity of both skidders (Fig. 2 and 3). From the ANOVA tables, both models were significant at $\alpha = 0.05$ (Tables 6 and 7). The model for the skidder TC 630C had a higher coefficient of determination compared to the model for the skidder TC 630D, and it could explain about 49% of the total variability observed for skidder productivity. The average productivity for the TC 630C skidder was about 28.53 GMt/PMH_0 which was lower than for the TC 630D skidder, with 31.69 GMt/PMH_0 although the skidder 630D covered a longer mean skidding distance (256 m vs. 190 m) (Table 8).

Table 4 Analysis of variance of productivity model for feller-buncher
Tablica 4. *Analiza varijance modela za izračun proizvodnosti feler bančera*

	Sum of Squares *Suma kvadrata*	Df *Stupnjevi slobode*	Mean Square *Varijanca*	*F* *F-vrijednost*	Sig. *Statistička značajnost*
Regression *Regresijski model*	8 502.33	1	8 502.33	52.35	0.00
Residual *Rezidual*	12 668.22	78	162.41	–	–
Total *Ukupno*	21 170.55	79	–	–	–

3.3.1 Productivity model for Skidder TC 630C
Model za izračun proizvodnosti skidera TC 630C

$$\text{Productivity (GMt/PHM}_0\text{)} = 34.559 - 0.032 \times \text{Skidding distance (m)}$$

$$R^2 = 49.0\%, \ n = 10$$

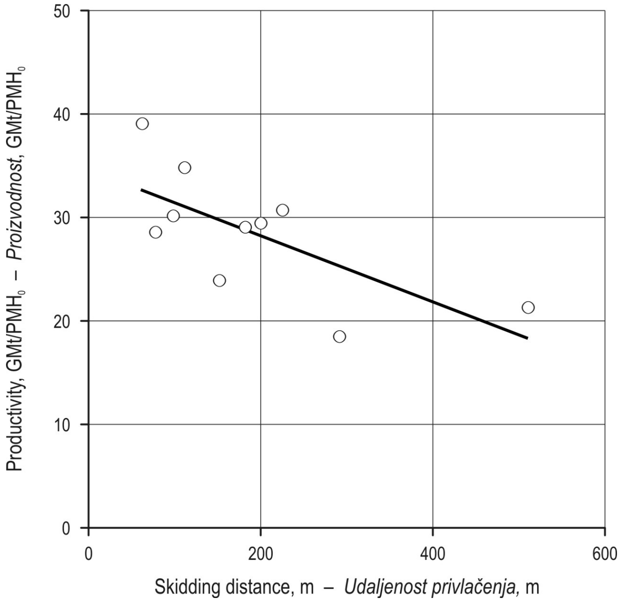

Fig. 2 Impact of skidding distance on the productivity of skidder TC 630C

Slika 2. *Utjecaj udaljenosti privlačenja na proizvodnost skidera TC 630C*

3.3.2 Productivity model for Skidder TC 630D
Model za izračun proizvodnosti skidera TC 630D

$$\text{Productivity (GMt/PHM}_0\text{)} = 37.214 - 0.020 \times \text{Skidding distance (m)}$$

$$R^2 = 38.9\%, \ n = 11$$

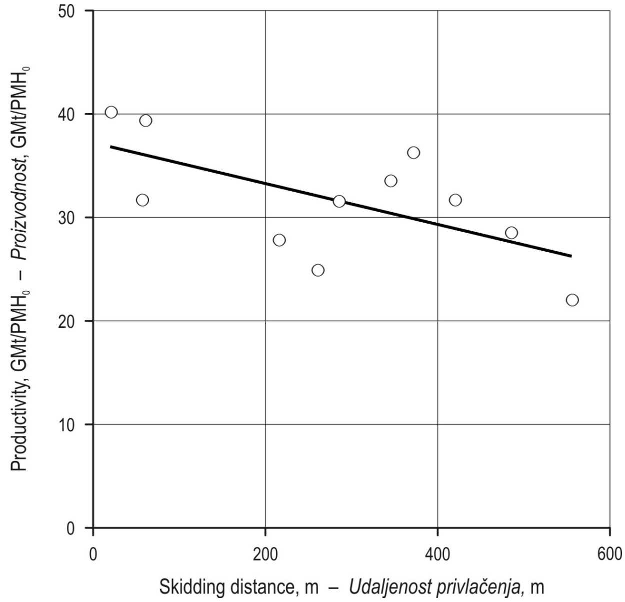

Fig. 3 Impact of skidding distance on the productivity of skidder TC 630D

Slika 3. *Utjecaj udaljenosti privlačenja na proizvodnost skidera TC 630D*

Table 5 Work element breakdown for the feller-buncher

Tablica 5. *Raščlamba radnih elemenata feler bančera*

	Positioning *Zauzimanje položaja*	Felling & bunching *Sječa i uhrpavanje*	Travel *Premještanje stroja*	Clearing *Raščišćavanje*	Delay *Prekid rada*
Share, % – *Udio*, %	0.3	95.5	4.0	0.2	0.0

Table 6 Analysis of variance of productivity model for skidder TC 630C

Tablica 6. *Analiza varijance modela za izračun proizvodnosti skidera TC 630C*

	Sum of Squares *Suma kvadrata*	Df *Stupnjevi slobode*	Mean Square *Varijanca*	*F* *F-vrijednost*	Sig. *Statistička značajnost*
Regression *Regresijski model*	163.17	1	163.17	7.68	0.024
Residual – *Rezidual*	170.01	8	21.25	–	–
Total – *Ukupno*	333.18	9	–	–	–

From Fig. 3, the longer the skidding distance the lower the productivity, due to the increased travel time.

The percent incidence of each work element on the skidding cycle for the two skidders is presented in Table 9. Nearly half of the work time was spent for clearing debris. The lowest percentage was for unloading, which accounted for less than 2% of the total skidding time. The delays were mainly due to waiting for the chipper to unload the bunches in front of the chipper to be accessible for the chipper grapple due to lack of free space (operational delays). The incidence of delays was 10 percentage points higher for the skidder 630D than for the skidder 630C.

3.3.3 Husky Precision flail and chipper – *Procesor i iverač Husky Precision*

The flail worked for 243 minutes, reaching the average productivity of 57.80 GMt/PMH_0. Debarking accounted for about 92% of total work time. Delays included waiting for wood (4.5% of total work time), warm up (1.6% of total work time) and waiting for chipper as the chipper was waiting for truck (2.0% of total work time).

The chipper discharged directly into the trucks. Four trucks were used to transport the chips to the APEC mill. The average delay-free chipping time per truck was about 56 minutes. Net productivity averaged 58.18 GMt/PMH_0. Effective chipping time accounted for 93 % of total work time. Delays were represented by waiting for wood (4.7% of total work time), waiting for trucks (0.2%) and warm up (2.0%).

3.3.4 Transportation – *Daljinski transport*

The transport distance from study area to the APEC mill gate was 58 km. Mean net productivity and the payload was 14.96 GMt/PMH_0 and 54 GMt, respectively. The average delay-free cycle time for transportation was about 4.58 hours. Elemental time breakdown for transportation is shown in Table 10. Traveling loaded had the highest incidence on total cycle time (28 %). Delays consisted almost exclusively of waiting.

3.3.5 Yield and chip quality – *Količina i kakvoća drvne sječke*

The study area (1.45 ha) yielded 232 GMt of pulp chips, corresponding to 160 GMt/ha. Based on moisture content sampling of 43%, the actual yield in dry mass was equal to 90 BDMt/ha (Mitchell and Wiedemann 2012).

The chip sample analysis showed that bark content was 0.18%, well within the limits set by APEC specifications (<0.5 %). Table 11 shows that 68% of the chip mass consisted of particles measuring between 9.5 mm and 22.2 mm (Mitchell and Wiedemann 2012).

3.3.6 Harvest residues assessment – *Procjena količine drvnoga ostatka*

Scattered stump site residues accounted for 6.4 GMt/ha. In contrast, flail residues returned to the field and stacked as »beehives« represented 262 m^3.

4. Discussion – *Rasprava*

The productivity of the feller-buncher in this case study is lower than the average productivity (138.0 GMt/PMH_0) reported for a similar Valmet 445 EXL tracked self-leveling feller-buncher working in the pine plantations of the South Gippsland coast of Victoria (Acuna et al. 2011). It is also lower than the 122.2 GMt/PMH_0 reported for the clear fell of pine plantation in Southern Tasmania (Ghaffariyan et al. 2012). The main reason for that is likely to consist in the smaller tree size handled in this study. The fuel consumption per cubic meter is also lower than the consumption reported for a large feller-buncher (0.36 l/GMt) by Johnson et al. 2006. It is also slightly lower than the consumption of 0.34 l/GMt reported by Ghaffariyan et al. 2012 for Southern Tasmania, which is consistent with the lower productivity. The close relationship between feller-buncher productivity and tree size in eucalypt clearfell operations is supported by the results obtained in Brazil by Moreira et al. (2004), who reported a productivity of 33.5 and 36.1 GMt/PMH_0 for an average DBH of 9.0 and 10.4 cm, respectively. Similar results are also reported by Spinelli et al. (2009) who studied a range of feller-bunchers used for eucalypt clearfell and obtained figures between 14 and 20 GMt/PMH_0 for smaller DBH and steeper slopes than covered by this study.

The average productivity of both skidders in this study is lower than the productivity (44.6 GMt/PMH_0) of a similar TC 730C grapple skidder used for extracting small whole eucalypt trees in Western Australia (Ghaffariyan et al. 2011).

Productivity rates in this study are also lower than the 47.5 GMt/PMH_0 reported for whole eucalypt tree skidding in Brazil (Valverde et al.1996). This could be the result of the longer skidding distance, smaller payload and residue clearing in our case study. The productivity models estimated by Dodson et al. (2006) for two Caterpillar rubber-tired grapple skidders working in western juniper stands included three independent variables, namely: skidding distance, number of stems per turn and a dummy variable for stand type (mixed or not-mixed). Our skidding productivity models contain the skidding distance as a significant variable affecting the skidder productivity.

Table 7 Analysis of variance of productivity model for skidder TC 630D
Tablica 7. *Analiza varijance modela za izračun proizvodnosti skidera TC 630D*

	Sum of Squares *Suma kvadrata*	Df *Stupnjevi slobode*	Mean Square *Varijanca*	*F* F-*vrijednost*	Sig. *Statistička značajnost*
Regression *Regresijski model*	125.02	1	125.02	5.72	0.04
Residual *Rezidual*	196.59	9	21.84	–	–
Total *Ukupno*	321.61	10	–	–	–

Table 8 Descriptive statistics of productivity model – Skidder TC 630C and TC 630D
Tablica 8. *Opisna statistika modela za izračun proizvodnosti skidera TC 630C i skidera TC 630D*

	Skidder type *Tip skidera*	Minimum *Najmanja vrijednost*	Maximum *Najveća vrijednost*	Mean *Aritmetička sredina*
Skidding distance, m *Udaljenost privlačenja,* m	TC 630C TC 630D	60.00 20.00	510.00 555.00	190.00 256.04
Tree size, m^3 *Obujam stabla,* m^3	TC 630C TC 630D	0.14 0.15	0.21 0.21	0.17 0.17
Productivity, GMt/PMH_0 *Proizvodnost,* GMt/PMH_0	TC 630C TC 630D	18.50 22.10	39.00 40.30	28.53 31.69

The productivity rates of both skidders in our case study are lower than reported productivity of 53.8 GMt/PMH_0 for a Caterpillar grapple skidder 525C in clear felling operations in Eucalypt stands with the average tree size of 0.178 m^3 and average skidding distance of 160 m (Wiedemann and Ghaffariyan 2010). The skidding distance was longer in our case study, which resulted in lower productivity. The average fuel consumption of the two skidders in this study (0.79 l/GMt) is higher than the fuel consumption reported by Makkonen (2004) for a grapple skidder used in Canada. However, it is also lower than reported for large clam bunk skidders (1.17 l/GMt) used in USA (Johnson et al. 2006).

Flail and chipper were two separate machines operated by two operators at the road side in this study. The chipper net productivity (58.18 GMt/PMH_0) is slightly lower than recorded for the Morbark chipper working at roadside (59.4 GMt/PMH_0) to chip logs from first thinning in Pine plantation of South Australia (Ghaffariyan 2012). Tree size and machine power in this study were higher than for the Morbark chipper trial, which should have resulted in higher productivity, based on the findings of Spinelli and Hartsough (2001). They found a direct relationship between chipper productivity, piece size and engine power. The lower chipping productivity in this study is likely due to the smaller tree bunches delivered to the chipper as

Table 9 Percent incidence of each work element on the total duration of the skidding cycle
Tablica 9. *Postotni udio pojedinoga radnoga elementa u ukupnom trajanju turnusa privlačenja*

	Skidder type *Tip skidera*	Clear debris *Čišćenje ostatka*	Travel empty *Vožnja praznoga*	Load *Utovar*	Travel loaded *Vožnja punoga*	Unload *Istovar*	Delay *Prekid rada*
Share, % *Udio*, %	TC 630C TC 630D	49 43	20 16	3 5	18 15	1 2	9 19

Table 10 Percent incidence of work steps on total transportation cycle
Tablica 10. *Postotni udio pojedinoga radnoga elementa u ukupnom trajanju turnusa daljinskoga transporta*

	Loading *Utovar*	Travel loaded *Vožnja punoga*	Unloading *Istovar*	Travel empty *Vožnja praznoga*	Delay *Prekid rada*
Share, % – *Udio*, %	22	28	13	23	14

Table 11 Particle size distribution of chip samples
Tablica 11. *Granulometrijska struktura uzoraka drvne sječke*

Size class *Razred*	>28.6 mm	>22.2 mm	>9.5 mm	>4.8 mm	<4.8 mm	Bark *Kora*
Share, % – *Udio*, %	3.36	16.31	68.24	9.88	2.03	0.18

a result of the hot-decking operation, where chipping/loading occurred at the time of wood extraction to the road side. In contrast, the Morbark chipper worked trees decked in large piles (average height and length of the piles were 4 m and 66 m, respectively), allowing for relatively large bunches of wood to be fed into the chipper. Another factor may be the impact of whole tree chipping (in our case study delimbed stems from whole trees by flail) versus log chipping (Spinelli and Magagnotti 2010). The productivity recorded in this study is also higher than reported for a Peterson Pacific chipper tested in whole tree chipping for biomass (33.90 GMt/PMH$_0$) in Western Australia, due to the smaller tree size of 0.10 m^3 in the latter study (Ghaffariyan et al. 2011). In our case study area only four trucks were loaded, and chipping and trucking were characterized by a very small sample size.

The amount of scattered stump-site residues (6.45 GMt/ha) was much lower than reported for sites harvested by the cut-to-length system. According to Smethurst and Nambiar (1990) stump-site residues amounted to 52 GMt/h in a clearfelled *Pinus radiata* plantation in Mount Gambier, South Australia. Similarly, Ghaffariyan and Andorovski (2011) report as much as 70.4 GMt/ha for the stump-site residues left after the cut-to-length clearfell harvesting of a *Eucalyptus nitens* plantation in Northern Tasmania. In our case study, it is important to determine whether the »beehives« are better spread over the whole site or if the flail residues could rather be refined and used as boiler fuel.

5. Conclusions – *Zaključci*

Based on these results, the inclusion of more machines will result in higher cost of operation and higher fuel consumption. In this case study, using two skidders increased total operating costs. Future studies could compare the use of two skidders with the use of one skidder only. Long skidding distance, small payload and spending time for clearing debris resulted in low productivity of the skidders in this case study. According to the results, the skidding distance had significant impact upon the productivity of two skidders. Based on the productivity predicting models, the larger the tree volume the higher the feller-buncher productivity.

As two separate machines were used for debarking (Husky flail) and chipping (Husky chipper), the future studies could also explore the efficiency of integrated delimber-debarker-chipper units, where the flail and chipper are combined into one machine, as an initial trial has indicated that using separate flail and chipper can result in higher total harvesting cost than using an integrated delimber-debarker-chipper (Ghaffariyan and Sessions 2012).

Roadside chipping operation left a small amount of residues in the stand, being based on whole tree-extraction. The possible impacts of intense slash removal on site fertility could also be studied in the future.

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Sažetak

Ocjena učinkovitosti, kakvoće drvne sječke i količine drvnoga ostatka pri proizvodnji drvne sječke procesorom i iveračem u Zapadnoj Australiji

Iveranje pokretnim iveračem na pomoćnom stovarištu uobičajen je sustav proizvodnje visokokvalitetne drvne sječke za celulozu u australskim šumskim plantažama. Istraživani sustav pridobivanja drvne sječke činili su feler bančer, dva skidera s kliještima za privlačenje uhrpane stablovine, procesor za kresanje grana i koranje, diskni iverač za usitnjavanje okorane deblovine i kamion za prijevoz proizvedene drvne sječke. Skideri su osim za privlačenje stablovine na pomoćno stovarište korišteni i za vraćanje drvnoga ostatka nastaloga pri proizvodnji drvne sječke u sječinu i njegovo uhrpavanje.

Istraživali su se proizvodnost, troškovi i utrošak goriva pojedinih strojeva u sustavu te kakvoća drvne sječke i količina drvnoga ostatka nakon pridobivanja drvne sječke.

Prosječna proizvodnost stroja za sječu i uhrpavanje iznosila je 97,26 GMt/PMH$_0$, a prosječna proizvodnost skidera iznosila je 60,22 GMt/PMH$_0$. Proizvodnost procesora i iverača iznosila je prosječno 57,80 GMt/PMH$_0$, odnosno 58,18 GMt/PMH$_0$. Prosječna proizvodnost daljinskoga transporta iznosila je 57,34 GMt/PMH$_0$.

Za konstrukciju modela za izračun proizvodnosti pojedinoga stroja u sustavu pridobivanja korišten je studij vremena i regresijske analize. Utvrđen je značajan utjecaj obujma stabla na proizvodnost stroja za sječu i uhrpavanje te udaljenosti privlačenja na proizvodnost skidera. Troškovi su procijenjeni primjenom modela ALPACA (Australian logging productivity and cost appraisal).

Ovaj rad donosi važne spoznaje o utjecaju različitih čimbenika na proizvodnost feler bančera te na proizvodnost skidera. Primjenom dvaju skidera u sustavu pridobivanja, nužnih za održavanje proizvodnosti ostalih strojeva u sustavu, nastao je visoki ukupni trošak. Pridobivanje sirovine za proizvodnju drvne sječke stablovnom metodom dalo je vrlo malu količinu drvnoga ostatka preostaloga u sječini.

Ključne riječi: pridobivanje drva stablovnom metodom, stroj za sječu i uhrpavanje, skider, procesor, trošak, drvni ostatak

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