Skidding of fir roundwood by Timberjack 240C from selective forests of Gorski Kotar

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Abstract

The aim of the research was to determine the productivity of the cable skidder Timberjack 240C equipped with double-drum winch Konrad Adler HY 16 during skidding of fir roundwood from the Croatian mountainous selective forests of fir and beech. The research took place in the area of Delnice Forest Management, at two workplaces with different degrees of stone obstacles provided with strip road network. Skidder productivity was determined by the method of time and work study.

The paper shows the results of some working characteristics of the researched skidder, such as: travelling speed of unloaded and loaded skidder, time consumptions of felling site work (loading) and roadside landing work (unloading), allowance time, realized load volume, fuel consumption, dependence of possible productivity and costs per unit on timber skidding distance.

Keywords: secondary openness, Timberjack 240C, productivity, cost per unit

1. Introduction – *Uvod*

Forestry machinery production is not developed in the Republic of Croatia and machines required by the Croatian forestry are purchased on the foreign market. These machines and equipment are usually designed to suit the working conditions of the producer's home country. Therefore, when purchasing these machines and equipment, it is not sufficient to make decisions on the basis of factory data and data on their productivity referred to in foreign literature but they should rather be tested in our own working conditions. The reason lies in specific relief, hydrographic and climate features of the Croatian forests, as well as in diversity of tree species, condition of stands and manner of forest management.

This paper deals with the research of primary off-road transport of roundwood by skidder Timberjack 240C. The purpose of this research is to give contribution to gaining knowledge of the productivity of a Timberjack 240C in extracting roundwood from Croatian mountainous selective forests.

Figure 1 Place of research
Slika 1. *Mjesto istraživanja*

2. Timber extraction – *Privlačenje drva*

In carrying out forest operations, terrain conditions determine the mobility of vehicles and people (Mellgren 1980, Conway 1984, Berg 1992). The limiting factors of forest operations in Croatian fir-beech mountainous stands are terrain slope, micro-relief with surface obstacles, bearing strength of deep soils during periods of increased moisture, snow and ice conditions in winter and stand conditions of selection-managed forests (Krpan & all. 1999). When speaking about economic forests in the mountainous area of the Republic of Croatia, the interest should be focused on natural, mixed and uneven-aged forests managed by selection felling, group and individual tree felling with a 10-year felling cycle. European silver fir (*Abies alba* Mill.), Norway spruce (*Picea abies* L.), European beech (*Fagus sylvatica* L.) and Sycamore maple (*Acer pseudoplatanus* L.) are the most important market species.

Forest harvesting in mountainous selection fir-beech stands is determined by the following characteristics:

- Felling and processing completely carried out by use of chain saws. For processing fir, hauling length method is used characterized by the length of assortments (4–12 m) adapted to the means of secondary transportation of wood, while beech is processed by use of cut-to-length method.
- Wood bunching and extracting is performed by skidders equipped with one-drum or double-drum winches (LKT 80, LKT 81, Silva, Timberjack 240 C) – they are used for skidding 95 % of all processed assortments (Sabo 2000).
- Secondary (further) transport of roundwood is mostly carried out by trucks and railway transport is not so common. For the transport of roundwood, different types of trucks are used with trailers or semi-trailers. Each truck is equipped with a hydraulic crane, installed behind the cabin or at the end of the extended chassis of the truck, depending on the type of the vehicle.

Due to the combined use of skidders and trucks for primary and secondary transportation of roundwood, forest harvesting had to rely on a network of forest and public roads. Forest roads are expected to reduce the distance and costs of wood extraction, and strip roads and skid trails to reduce winching and mobility of loaded vehicles on mountainous terrain of higher or lower slope.

Strip roads and skid trails in fir-beech selection stands represent the basic network of secondary forest openness, which provides the quickest and shortest way to felled and processed trees. Forest opening through a system of strip roads and skid trails rationalizes the felling site work providing the achievement of cost efficient felling, processing and wood extraction. Strip roads and skid trails are constructed on forest terrain with the slope gradient ranging between 30 and 60 % with the terrain stone content, due to karst conditions, reaching up to 90 %. With fine stand opening through a network of skid roads, the optimum openness ranges between 100 and 200 m/ha. In the system of secondary stand openness with higher density of skid roads, their spatial distribution in the forest area is determined by terrain configuration.

3. Double drum cable skidder Timberjack 240C – *Zglobni traktor s dvobubanjskim vitlom Timberjack 240C*

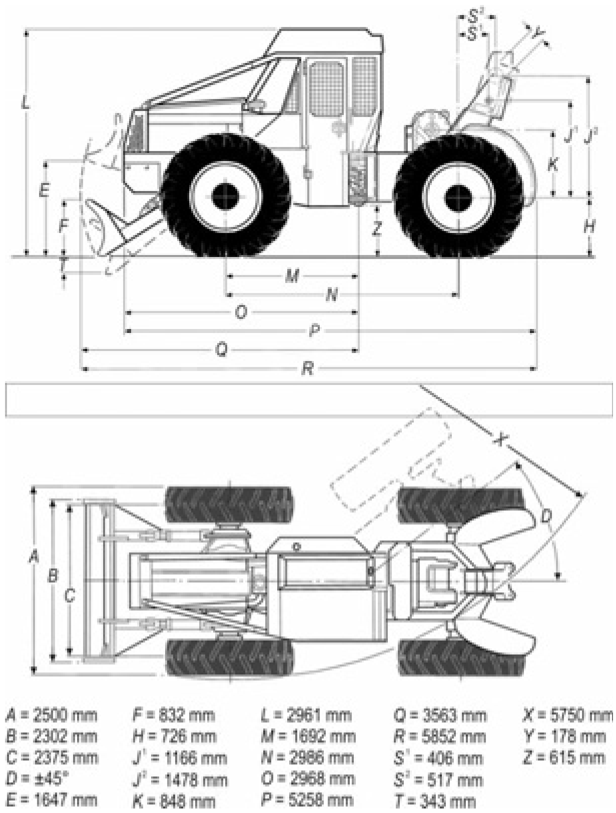


Figure 2 Basic dimensions

Slika 2. *Osnovne dimenzije*

Cable skidder Timberjack 240C is a four-wheel drive vehicle. It is designed for skidding timber on strip roads and skid trails as well as off road, which implies that one end of the dragged roundwood is in touch with the ground. Timber bunching is carried out by the winch installed in the rear part of the skidder from the stump to the skidder.

The basic characteristics of the skidder Timberjack 240C are as follows:

- The mass of unloaded skidder is 8409 kg (58 % on the front and 42 % on the rear axle).
- Cummins 4BTA engine is a 4-cyliner, diesel engine with turbo charger, which generates a

power output of 75 kW at 2200 min^{-1} and 423 Nm of torque at 1500 min^{-1}.
- Skidder dimensions are shown schematically in Figure 2.
- The winch is double drum Konrad Adler HY 16 type, with a mass of 560 kg and tractive force of 80–48 kN depending on the length of the cable pulled off the winch. The cable is 16 mm in diameter and 50 m in length per drum. The winch is powered mechanically and steered electro-hydraulically.
- The front blade is adjustable, 2016 mm in width, operated hydraulically. It is designed for bunching roundwood at roadside landing.
- The front and rear tires are of the same dimensions – 18.4-34 Firestone.

4. Study Site – *Mjesto istraživanja*

The research of the extraction of fir roundwood by skidder Timberjack 240C was carried out in mountainous conditions of fir-beech selection forests in the area of Delnice Forest Administration. This area makes part of Dinaric Alps with specific geo-morphological, climate and vegetation characteristics. The relief of Gorski Kotar is characterized by carbonate rocks (limestone and dolomite) and their numerous karst forms: ridges, crests, crags, karst valleys, basins, transverse valleys, round karst valleys, cracks in limestone, caves, abysses, underground flows, karst wells and springs (Sabo 2001). Delnice Forest Administration manages a forest area of 96,009 ha with the growing stock of 25,650,751 m^3. The annual increment is 489,724 m^3 and the annual harvesting volume is 386,704 m^3. The average primary forest openness is 21.3 m/ha and the secondary 71 m/ha. Terrain stoniness was the key criteria for selecting the workplaces where the research was to be carried out, since stoniness is one of the limiting factors for performing forest operations in Dinaric fir-beech forests.

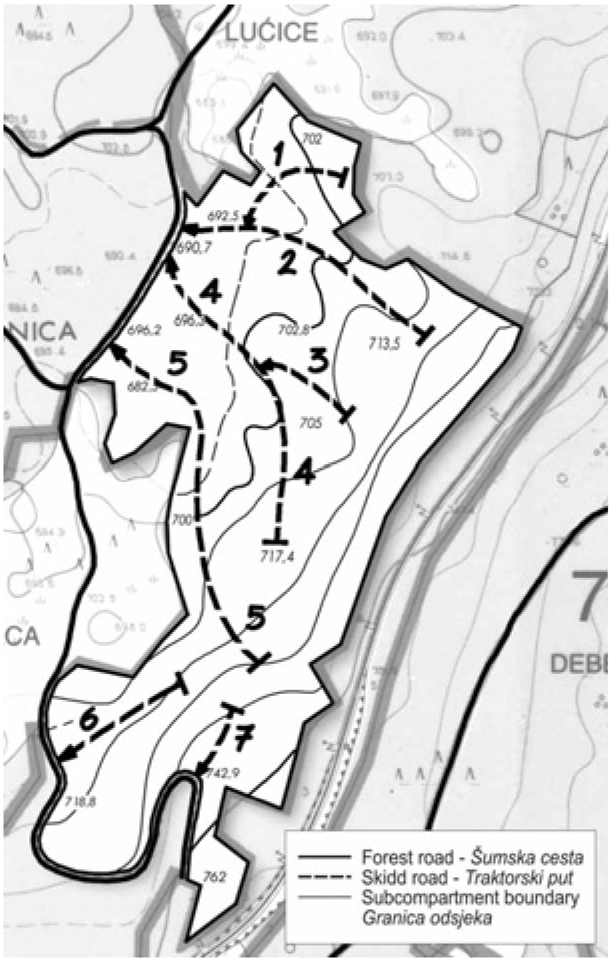


Figure 4 Subcompartment 74b
Slika 4. *Odsjek 74b*

The research involved two workplaces with different degree of stoniness in Delnice Forest Administration, Delnice Forest Office and namely: subcompartment 31b (no terrain stoniness) and 74b (terrain stoniness of up to 50%). Through the analysis of the results of skidder performance at both workplaces, comparison will be made between the realized values and result differences will be identified.

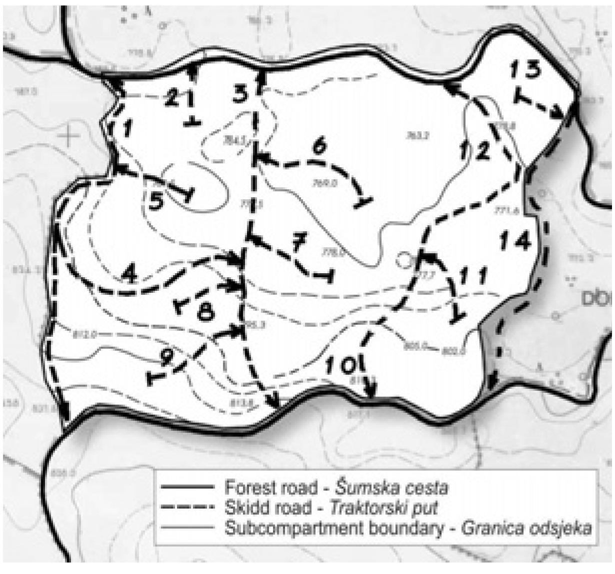


Figure 3 Subcompartment 31b
Slika 3. *Odsjek 31b*

Figure 3 and 4 show the maps of the investigated subcompartments; Figure 5 shows the structure of the growing stock by tree species before felling; and Figure 6 shows the structure of marking trees for felling depending on BHD classes. All the other characteristics of the investigated felling sites are given comparatively in Table 1.

Table 1 Features of subcompartments
Tablica 1. *Značajke odsjeka*

	Subcompartment – *Odsjek*	
	31b	74b
General characteristics – *Osnovne značajke*		
Area – *Površina*, ha	24.6	12
Exposition – *Izloženost*	N	NW
Terrain inclination – *Nagib terena*, °	10–25	0–20
Altitude – *Nadmorska visina*, m	770–805	690–760
Stoniness, % of area – *Kamenitost*, %	0	< 50
Mean extraction distance, m *Srednja udaljenost privlačenja drva*, m	200	200
Primary openness (forest roads), m/ha *Primarna otvorenost (šum. ceste)*, m/ha	38.6	25.0
Secondary openness (strip roads), m/ha *Sek. otvorenost (trakt. putovi)*, m/ha	96.4	111.7
Slope of strip roads, % *Nagib traktorskih puteva*, %	+32% – –34%	+8% – –16%
Stand features – *Sastojinske značajke*		
Growing stock – *Drvna zaliha*, m^3/ha	501.3	504.0
Basal area – *Temeljnica*, m^2/ha	32.7	38.6
No. of trees per ha – *Broj stabala po ha*	338	408
Stocking – *Obrast*	0.97	1.03
Harvesting characteristics – *Eksploatacijske značajke*		
Harvesting density, m^3/ha *Sječna gustoća*, m^3/ha	54.2	70.0
Harvesting density, trees/ha *Sječna gustoća*, stabala/ha	17	18
Mean cutting tree, m^3/tree *Srednje sječno stablo*, m^3/stablo	3.2	3.9
Distance among cut trees, m *Udaljenost između posječenih stabala*, m	24.3	23.8

The research took place in May and June of 2000. Felling of beech in subcompartments was not carried out because there is no supply of beech during summer. Felling of fir was carried out so that damaged and low-quality trees were cut by individual tree felling and the need for natural regeneration was obtained by group felling of trees.

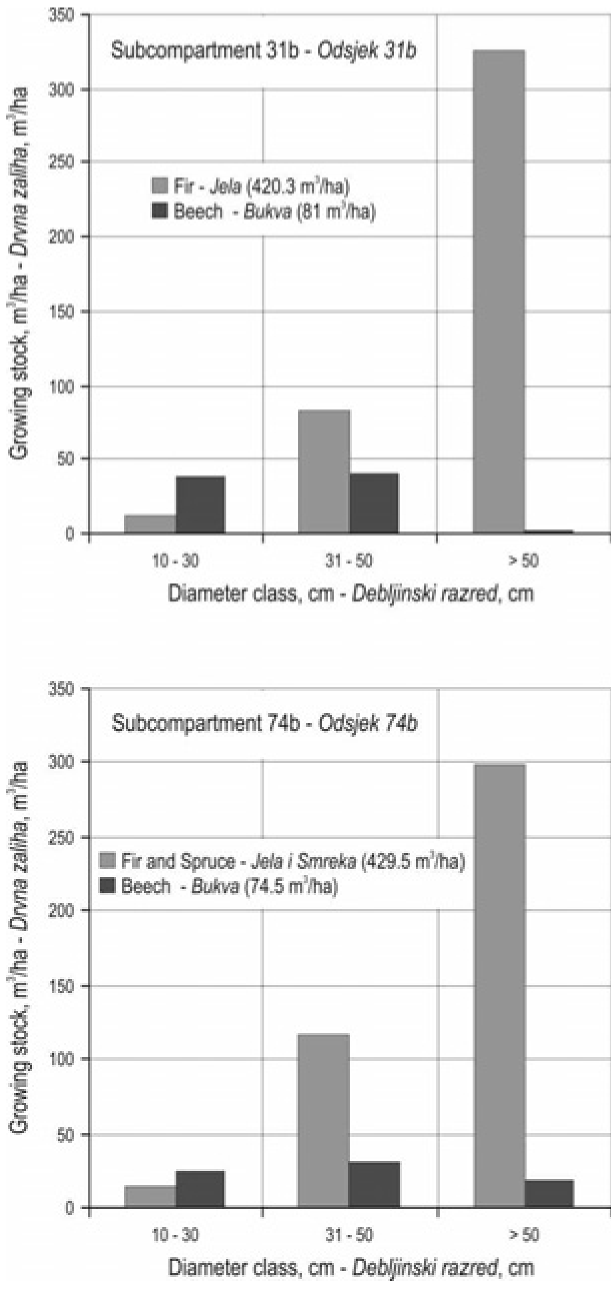


Figure 5 Structure of growing stock
Slika 5. *Struktura drvne zalihe*

Sink holes and terrain slope are the limiting terrain factors for performing forest operations. In subcompartment 74b, surface stones are mostly in the form of small and medium-size blocks. The soil is rendzic leptosol on limestone and during research it was dry and had good bearing strength. Roadside landings were situated along the roads laid on the edges of subcompartments; in subcompartment 31b their size was satisfactory and in subcompartment 74b they were narrow and lacked overview.

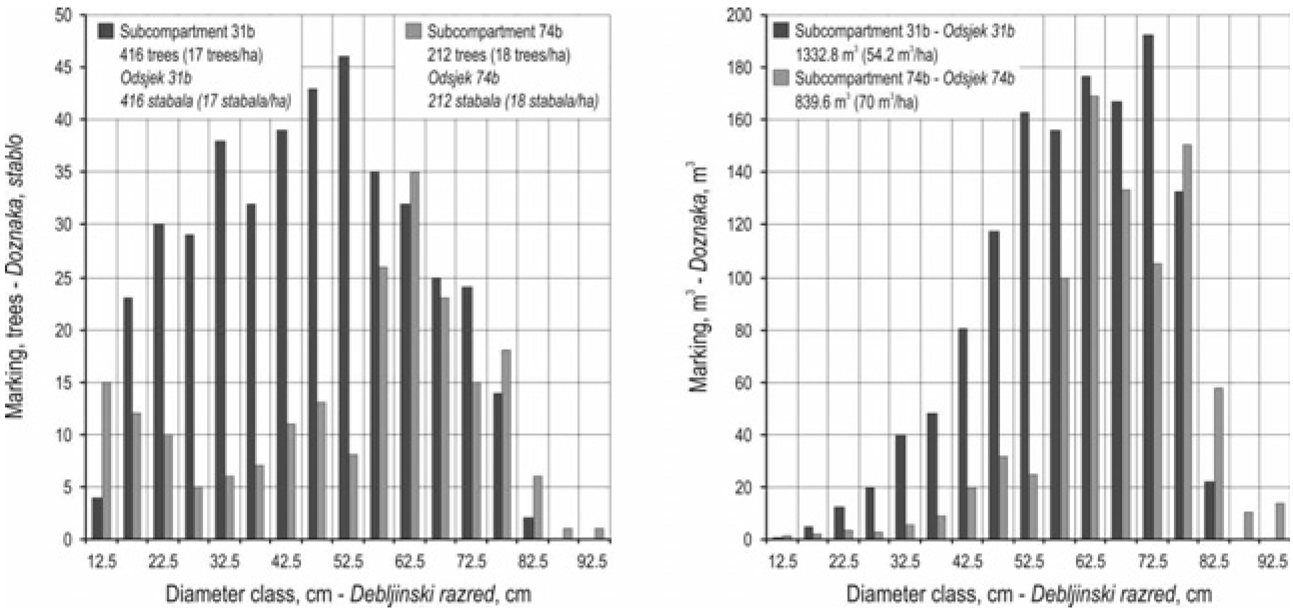


Figure 6 Structure of tree marking

Slika 6. *Struktura doznake stabala*

5. Data Collection and Analysis – *Prikupljanje i analiza podataka*

Skidder performance was investigated by time and work study method. The time used for timber extraction was divided into work components with pre-selected fixed points, which were in accordance with the set scope of research. Time consumptions of the duration of working components were researched by snap-back chronometry method and records were taken throughout the whole working day. The distances of unloaded and loaded travel were measured by use of a measuring tape, the slope gradient of the terrain and strip roads was measured by clinometer and the load data were collected by measuring the diameter and length of each piece of roundwood under bark.

The measurement data were entered into computer files from the field record sheets so as to make them available for data processing. Data processing covered the control and selection of data, classification of recorded times and calculation of the achieved work productivity. Mathematical/statistical data processing was carried out by use of a PC with the application of the software package Microsoft Excel 97 and Sta Soft Statistica 5.0.

Different measures of the central dispersion tendency of measurement data were studied with independent variables and median and arithmetical mean value were chosen as the most favourable ones and the standard deviation as the measure of dispersion of this value.

Stochastic dependence between the independent and dependent variables was determined by regression analyses. The selection of the regression curves was carried out on the bases of the following parameters: coefficient of correlation (R), standard deviation of the dependence variable around the regression line as well as t-variable and the probability of first grade error of regression coefficients (Kachigan 1991). Roemer-Orphal's scale was used for establishing the connecting force between the independent and dependent variables.

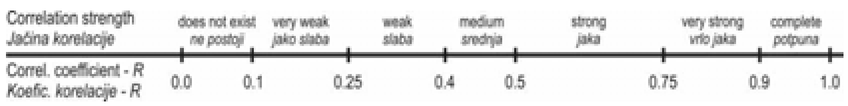


Figure 7 Roemer-Orphal's scale

Slika 7. *Roemer-Orphalova raspodjela*

6. Skidder operations – *Način rada traktora*

At the beginning of the working day, the driver would prepare the skidder for the work. After finishing the unloaded travel on strip road, the driver would position the skidder for load winching. The hooker would pull out the cable and hook the load. Having finished winching, the load would be adjusted in the right direction. In view of the number of load pieces, the skidder would take a new position and repeat the operations. After bunching the load, roundwood would be skidded on strip road to the roadside landing. The hooker would stay in the forest to prepare a new load. At the roadside landing, the driver would unhook the load, pull out the cable, wind it up on the drum and bunch the wood with the front blade. After finishing the operations at the roadside landing, a new cycle would begin. At the end of the working day, the skidder would be examined so as to eliminate possible faults and it would be cleaned and lubricated.

Figure 8 Loaded skidder travel

Slika 8. *Kretanje opterećenoga traktora*

7. Results of research – *Rezultati istraživanja*

Research of timber extraction by skidder Timberjack 240C at the cut-blocks is shown through achieved results such as: load parameters, structure of total and effective time, structure of delay times and allowance time, skidder travel speed, work time consumptions at the felling site and roadside landing and fuel consumptions. In the same way, possible productivities are shown depending on timber extraction distance and other factors affecting timber extraction.

7.1 Load features – *Značajke tovara*

Table 2 shows the data related to realized load volumes, number of roundwood pieces in the load and dimensions of extracted roundwood by researched cutblocks.

When comparing the mean values of load parameters of the investigated workplaces, it can be seen that there are no differences at all or that they are very small.

Table 2 Load parameters

Tablica 2. *Značajke tovara*

Statistical parameters	Load volume *Obujam tovara*	Pcs. in Load *Komada u tovaru*	Dimensions of roundwood – *Dimenzije oblovine*		
			Diameter – *Promjer*	Length – *Duljina*	Volume – *Obujam*
	m^3	pcs. – *kom.*	cm	m	m^3
Delnice Management Unit, subcompartment 31b – *Gospodarska jedinica Delnice, odsjek 31b*					
Count – *Veličina uzorka*	143	143	754	754	754
Sum – *Suma opažanja*	597,6	754	25991	5284	597,6
Median – *Medijan*	4,31	6	32	8,0	0,53
Mean – *Aritmetička sredina*	4,2 ± 1.7	5.3 ± 1.7	34 ± 15	7.0 ± 1.9	0.8 ± 0.7
Minimum – *Najmanja vrijednost*	0,08	1	10	2,0	0,03
Maximum – *Najveća vrijednost*	8,97	8	96	15,0	4,96
Delnice Management Unit, subcompartment 74b – *Gospodarska jedinica Delnice, odsjek 74b*					
Count – *Veličina uzorka*	118	118	670	670	670
Sum – *Suma opažanja*	522	670	22641	4709	522
Median – *Medijan*	4,55	6	33	8,0	0,57
Mean – *Aritmetička sredina*	4.4 ± 1.5	5.7 ± 1.3	34 ± 15	7.0 ± 1.7	0.8 ± 0.7
Minimum – *Najmanja vrijednost*	0,37	2	10	2,0	0,03
Maximum – *Najveća vrijednost*	7,67	8	77	14,0	3,85

Tests of differences between mean values of load parameters (Table 3) showed that at a 5 % significance level, difference was only recorded with the number of roundwood pieces in the load. However, due to such an extremely small difference between t_{CAL} (2.17) and t_{CRIT} (1.96), the actual difference may be neglected.

Table 3 Test of load parameters

Tablica 3. *Testiranje značajki tovara*

Tested *Testiranje*	t_{CAL}	*P*	Significance *Signifikantnost*
Load volume *Obujam tovara*, m³	–1,2490	$P > 0,05$	Does not exist *Ne postoji*
Pcs. in Load *Komada u tovaru*	–2,1716	$P < 0,05$	Exists *Postoji*
Dimensions of roundwood – *Dimenzije oblovine*			
Diameter *Promjer*, cm	0,8591	$P > 0,05$	Does not exist *Ne postoji*
Length *Duljina*, m	–0,2131	$P > 0,05$	Does not exist *Ne postoji*
Volume *Obujam*, m³	0,3621	$P > 0,05$	Does not exist *Ne postoji*

In further analyses, the medians calculated based on the samples from both workplaces will be taken as the mean value of the load parameters. It can be concluded that at both workplaces the average load volume was 4.4 m^3 and consisted of 6 pieces of roundwood. The volume of an average piece of roundwood was 0.6 m^3 and it was 8 m long.

7.2 Realised productivity and structure of total and effective time – *Ostvareni učinak te struktura ukupno utrošenoga i efektivnoga vremena*

Skidder performance was being observed at both workplaces for 16 working days. During that time 1,119.6 m^3 of timber was extracted in 261 recorded cycles. The survey of total time consumption by working components, realized average productivities and total and effective time consumptions per m^3 for all felling sites is given in Table 4.

There is no great difference between the average productivity at workplaces (31b – 11.3 m^3/h, 74b – 11.3 m^3/h) or between total times (31b – 5.32 min/m^3, 74b – 5.18 min/m^3) or effective times (31b – 3.59 min/m^3, 74b – 353 min/m^3) per unit.

The delay times are shown by the ratio between delay time and effective time. This ratio between delay time and effective time is 0.481 (31b) and 0.467 (74b), respectively.

The share of effective time ranges between 67.5 % (31b) and 68.2 % (74b) of total time and delay times (unavoidable and avoidable delay times) range between 31.8 % (74b) and 32.5 % (31b).

Due to different travelling distances on strip roads of the investigated workplaces (31b – 170 m 74b – 130 m) as well as on forest roads in the area of landing (31b – 50 m, 74b – 25 m), the analysis of work components shares in effective time is more favourable.

Table 4 Structure of total time consumptions

Tablica 4. *Struktura ukupno utrošenih vremena*

Work components – *Radne sastavnice*	Subcompartment – *Odsjek*	
	31b (150 m)	74b (120 m)
	Time consumption – *Utrošak vremena*, min	
Unloaded skidder travel – *Vožnja neopterećenog traktora*	299.47	204.55
Strip road – *Traktorski put*	258.39	182.01
Roadside landing – *Pomoćno stovarište*	41.08	22.54
Loaded skidder travel – Vožnja opterećenog traktora	426.17	280.83
Strip road – *Traktorski put*	353.30	225.85
Roadside landing – *Pomoćno stovarište*	72.87	54.98
Felling site work – *Rad u sječini*	956.75	856.49
Work with winch – *Rad s vitlom*	799.51	733.16
Pulling out of cable – *Izvlačenje užeta*	202.81	156.15
Load hooking – *Vezanje tovara*	399.17	441.31
Winching – *Privitlavanje*	197.53	135.70
Work without winch – *Ostali radovi u sječini*	157.24	123.33
Positioning – *Zauzimanje položaja*	89.01	71.33
Load adjusting – *Ispravljanje tovara*	68.23	52.00
Roadside landing work – *Rad na pomoćnom stovarištu*	465.00	502.12
Moving up and down – *Silaženje i penjanje*	74.73	70.63
Load unhooking – *Odvezivanje tovara*	141.05	150.69
Pulling out of cable – *Izvlačenje užeta*	67.77	37.75
Deck bunching – *Uhrpavanje složaja*	148.51	210.64
Turning the skidder – *Okretanje traktora*	32.94	32.41
Effective time – *Efektivno vrijeme*, min	2147.39	1843.99
Delay time – *Opća vremena*, min	1033.77	861.46
Total time – *Ukupno utrošeno vrijeme*, min	3181.16	2705.45
Ratio Delay / Effective time – *Odnos općega i efektivnoga vremena*	0.481	0.467
Total skidded volume – *Ukupno privučeno drvo*, m³	597.6	522.0
Ratio Terminal / Travel time – *Odnos fiksnoga i varijabilnoga vremena*	1.96	2.80
Effective time per unit – *Efektivno vrijeme po jedinici*, min/m³	3.59	3.53
Total time per unit – *Ukupno vrijeme po jedinici*, min/m³	5.32	5.18
Productivity – *Ostvareni učinak*, m³/h	11.3	11.6

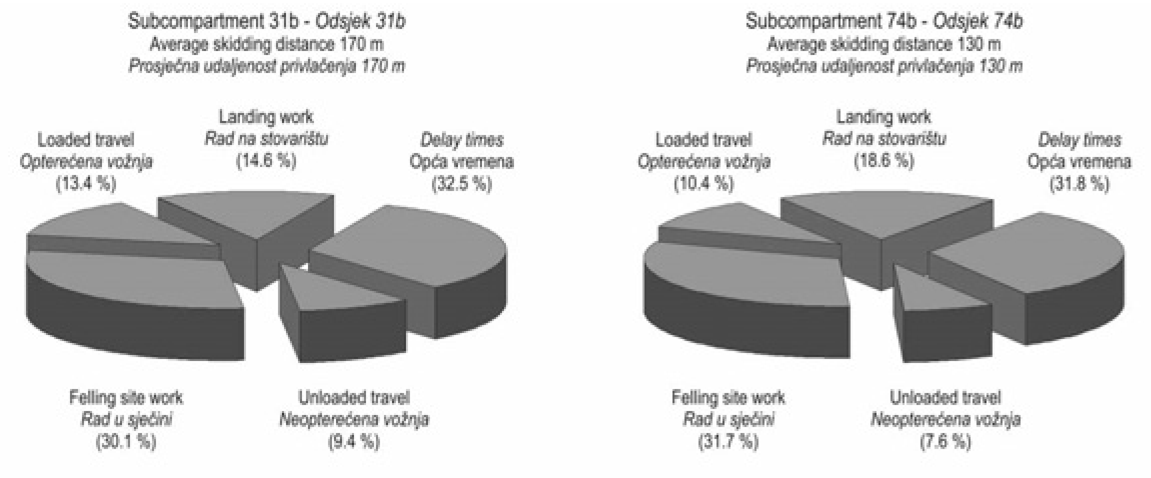


Figure 9 Structure of total time

Slika 9. *Struktura ukupno snimljenoga vremena*

Travel times depend on unloaded and loaded travel distance as well as on other influencing factors. The share of travel times in effective time for the workplace 31b with higher average skidding distance (170 m) was 33.8 % and travel times accounted for 26.3 % of effective time for the workplace 74b over an average skidding distance of 130 m. At both workplaces the share of loaded vehicle travel was higher than the share of the unloaded one and the analysis of the share of unloaded and loaded travel of the skidder in view of the travel base (strip road, forest road with crushed stone cover in the area of roadside landing) shows that strip road travel prevails.

Terminal times are made of skidder felling site (loading) and roadside landing (unloading) work times. The share of terminal time in the structure of effective time is strongly affected by skidding distance and other influencing factors. The impact of skidding distance is confirmed by the share of terminal times of 66.2 % at workplace 31b and of 73.7 % at workplace 74b with the shorter skidding distance.

The impact of skidding distance on the structure of the main groups of work components of effective time can be seen from the ratio between terminal and travel time. At the workplace with higher skidding distance (31b) it is 1.96 and at the workplace 74b the coefficient is higher – 2.80.

7.3 Structure of delay times and allowance time – *Struktura općih vremena i dodatno vrijeme*

Delay times (work breaks) consist of unavoidable and avoidable work breaks and efforts are made to minimize them to the necessary level by technologi-

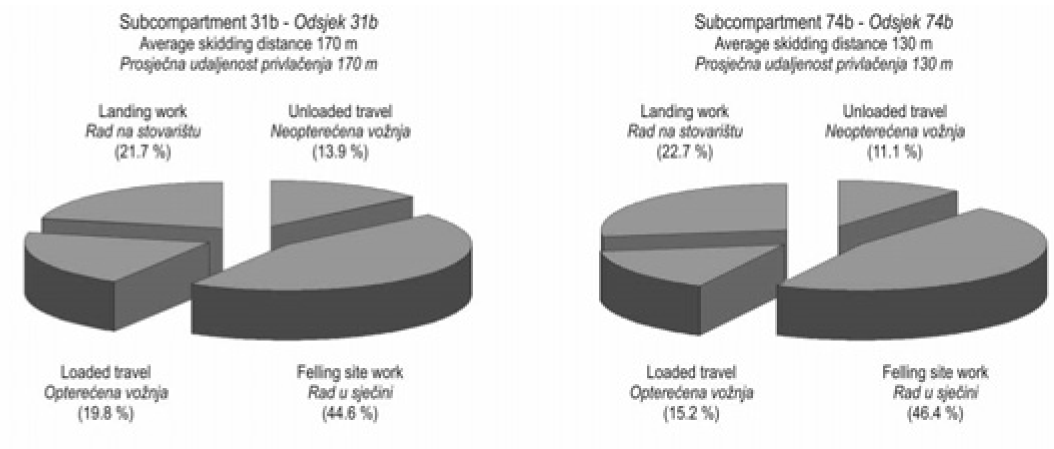


Figure 10 Structure of effective time

Slika 10. *Struktura efektivnoga vremena* cal and organizational measures. By excluding the avoidable breaks from delay times, allowance time is determined as an absolute value. Allowance time is calculated based on effective time to which it is added in the form of percentage or factor of allowance (Samset 1988). Ordinary delay times are usually not processed by statistical methods and they are rather investigated within the internal structure of total consumption time and allowance time (Fig. 11). Methods of analysis, comparison and synthesis method are used for processing delay times as well as for other data.

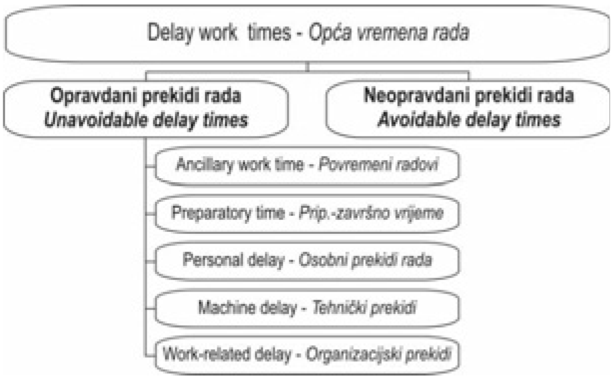


Figure 11 Structure of delays

Slika 11. *Raščlamba općih vremena*

Table 5 Structure of delays and allowance time

Tablica 5. *Struktura općih vremena i dodatno vrijeme*

Structure of delay times *Raščlamba općih vremena*	Subcompartments – *Odsjeci*			
	31b		74b	
	min	%	min	%
Ancillary work time *Povremeni radovi*	56.06	5.4	34.03	4.0
Preparatory time *Pripremno-završno vrijeme*	83.80	8.1	81.95	9.5
Personal delay *Osobni prekidi rada*	269.78	26.1	233.05	27.1
Machine delay *Tehnički prekidi*	5.63	0.5	1.19	0.1
Work-related delay *Organizacijski prekidi*	25.68	2.5	28.45	3.3
Unavoidable delay time *Opravdani prekidi rada*	440.95	42.7	378.67	44.0
Avoidable delay time *Neopravdani prekidi rada*	592.82	57.3	482.79	56.0
Delay time *Opća vremena*	1033.77	100.0	861.46	100.0
Allowance time (% of eff. time) *Dodatno vrijeme (% od efektivnoga vremena)*	20.53		20.54	

Avoidable delay times took the highest share in the structure of delay times (56 % in subcompartment 31b and 57.3 % in subcompartment 74b). Most part of delay times at both workplaces was random or caused by unsatisfactory (uncompleted) preparatory works.

Allowance time is calculated as the ratio between unavoidable delay times and effective time consumptions and it is expressed as percentage of effective time. Allowance time of 20.53 % and 20.54 % was calculated at workplace 31b and 74b, respectively. There is no significant difference between them.

7.4 Skidder travel times – *Varijabilna vremena rada traktora*

Travel time consumptions of unloaded and loaded skidder depending on travel distance will be investigated by regression analysis in view of whether the vehicle travels on forest off-road terrain or on constructed roads (forest road with crushed stone cover). Travel times of loaded vehicles will be investigated against load volume.

During research, the skidder only travelled on constructed roads and consequently travel times (time consumptions of unloaded and loaded skidder depending on travelling distance) were observed relative to the fact whether the unloaded/loaded skidder travelled on strip roads or on forest roads in the area of roadside landing.

7.4.1 Time consumptions and travel speeds of skidder on strip road – *Utrošci vremena i brzine kretanja traktora po traktorskom putu*

Travel time consumptions on strip road depending on travelling distance are shown in Figure 12A and 12B for unloaded skidder and loaded skidder, respectively. The figures clearly show mixing of recorded data at both workplaces, which caused regression analysis of all data in the sample.

Travel time consumptions depending on travelling distance are regressed with straight line from origin ($y = b \cdot x$). The complete correlation of data was obtained for unloaded skidder (R^2 = 0.903, s_{YX} = 0.31). Regression of travel times of loaded skidder shows a very strong correlation (R^2 = 0.803), with a little higher standard deviation around regression line (s_{YX} = 0.57), which is the consequence of skidded load volume variability. Average travel speeds are calculated on the basis of regressed travel times and travelling distances with values of 5.33 km/h for unloaded skidder and 3.99 km/h for loaded skidder (or 25.1 % lower).

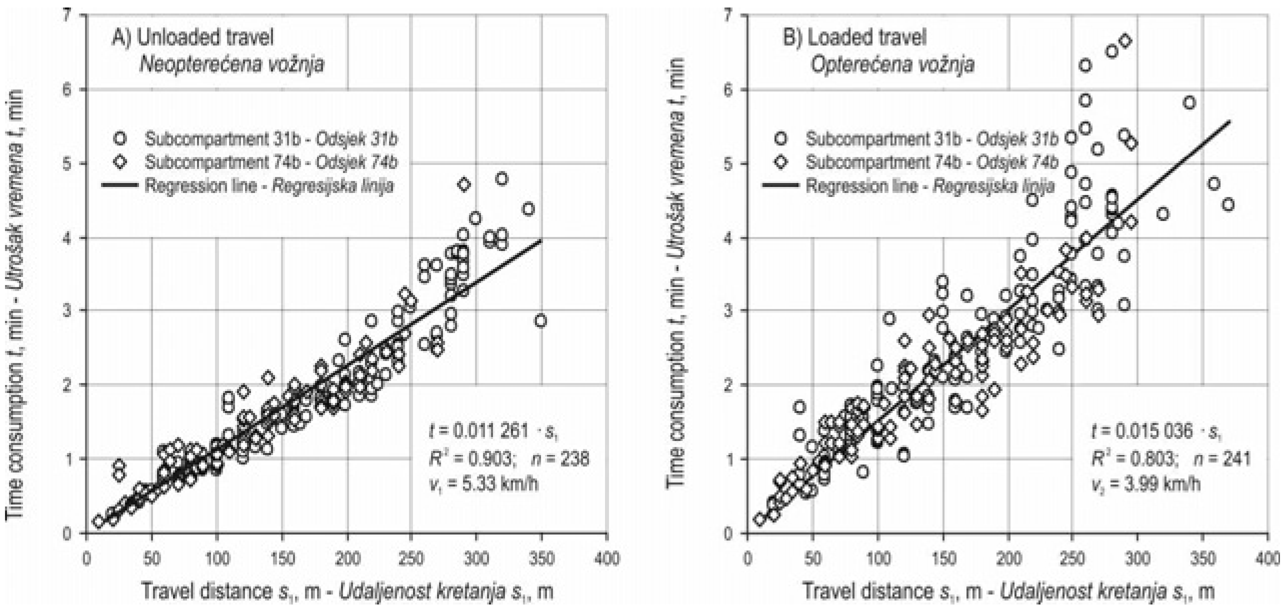


Figure 12 Strip road travel times

Slika 12. *Utrošci vremena kretanja po traktorskome putu*

7.4.2 Time consumptions and travel speeds of skidder on roadside landing – *Utrošci vremena i brzine kretanja traktora po pomoćnom stovarištu*

Skidder travel times on forest roads in the area of roadside landing depending on the travelling distance are shown in Figure 13A and 13B for unloaded skidder and loaded skidder, respectively.

Large range of time consumptions was caused by sorting timber in piles, presence of the truck during timber loading and ancillary works. Very strong correlations are obtained by regression of travel times of unloaded (R^2 = 0.892, s_{YX} = 0.05) and loaded skidder (R^2 = 0.783, s_{YX} = 0.12) with straight line from origin. The average travel speed of unloaded skidder in the area of roadside landing is 8.77 km/h and with loaded skidder it is by 46.5 % lower (4.69 km/h).

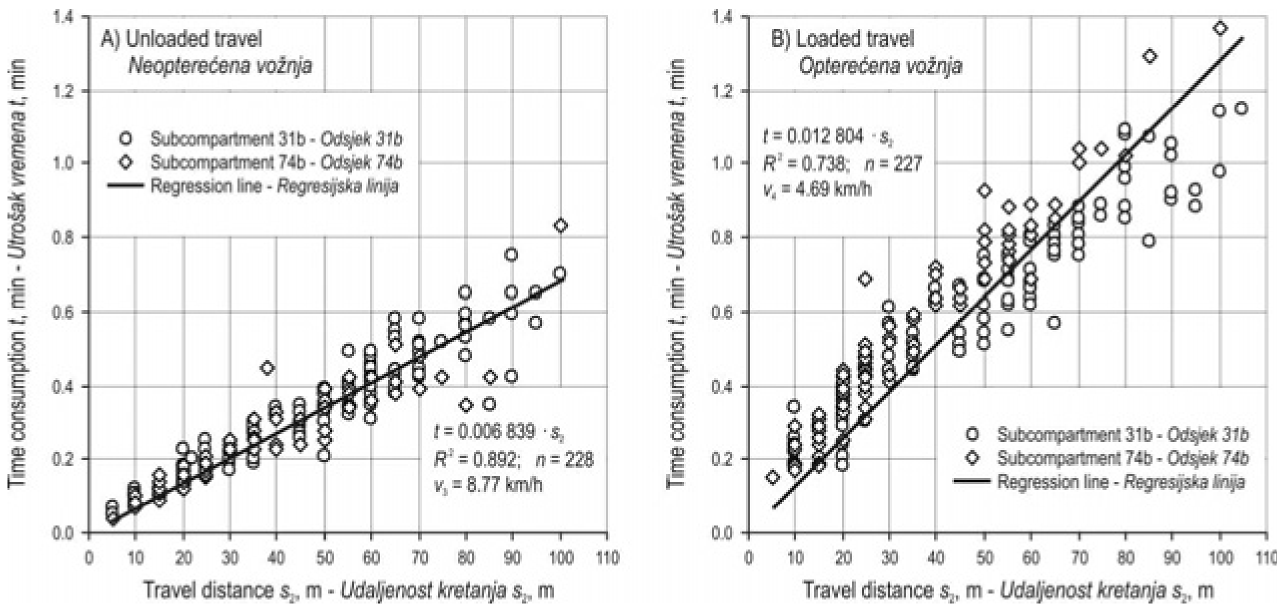


Figure 13 Roadside landing travel times

Slika 13. *Utrošci vremena kretanja po pomoćnom stovarištu*

7.5 Skidder terminal times – *Fiksna vremena rada traktora*

Terminal times of skidder work in timber skidding consist of the skidder felling site (loading) and landing (unloading) work time and their characteristic is that they are not affected by the skidding distance. Statistical analysis of the work components of terminal time consumptions at the level of skidder cycle (Table 5) showed their average values for both researched workplaces. The average realized work terminal time consumptions were: 9.94 ± 3.34 min/cycle (31b) and 11.51 ± 3.22 min/cycle (74b). As the difference of terminal time consumptions between the examined workplaces is only 1.57 min/cycle it is more appropriate to analyze individually time consumptions of the skidder felling site and landing work within the same skidder cycle.

Table 5 Statistical analysis of terminal time consumptions

Tablica 5. *Statistička analiza utrošaka fiksnih vremena*

Statistical parameters *Statističke veličine*	Felling site work *Rad na sječini*		Landing work *Rad na stovarištu*	
	31b	74b	31b	74b
	Time consumptions – *Utrošci vremena*, min			
Count *Veličina uzorka*	143	118	143	118
Sum *Suma opažanja*	956.75	856.49	465.00	502.12
Median *Medijan*	6.39	7.11	3.31	4.08
Mean *Aritmetička sredina*	6.69±2.54	7.26±2.36	3.25±1.25	4.26±1.42
Minimum *Najmanja vrijednost*	1.21	2.59	0.19	0.29
Maximum *Najveća vrijednost*	13.92	17.68	8.41	8.61

The difference of 0.57 min/cycle (0.04 min/m^3) was established in felling site work and of 1.01 min/cycle (0.18 min/m^3) in landing work between the two workplaces.

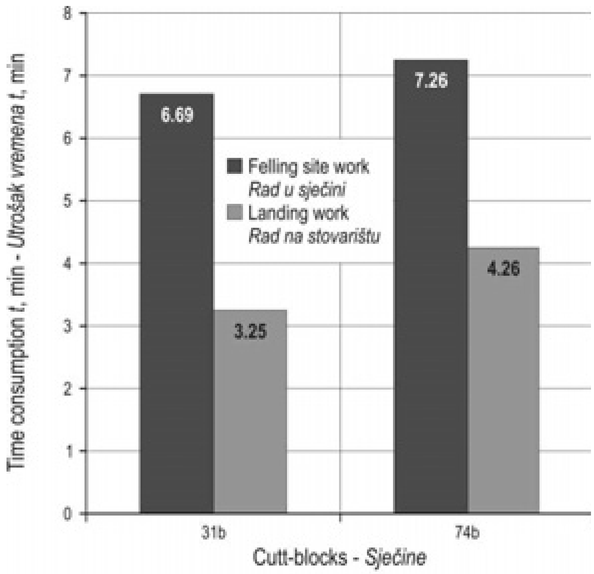
Testing of differences between the mean values of two main work component groups of terminal times (Table 6) showed that at a 5 % significance level, difference was only established in roadside landing work.

Since there is no significant difference in time consumptions of the skidder felling site work nor in realized load parameters between the two investigated workplaces, it can be concluded that time consumption of this group of work components is

Table 6 Test of terminal times

Tablica 6. *Testiranje fiksnih vremena*

Tested *Testiranje*	t_{CAL}	*P*	Significance *Signifikantnost*
Felling site work *Rad na sječini*	–1.8670	$P > 0.05$	Does not exist *Ne postoji*
Landing work *Rad na stovarištu*	–6.0024	$P < 0.05$	Exists *Postoji*



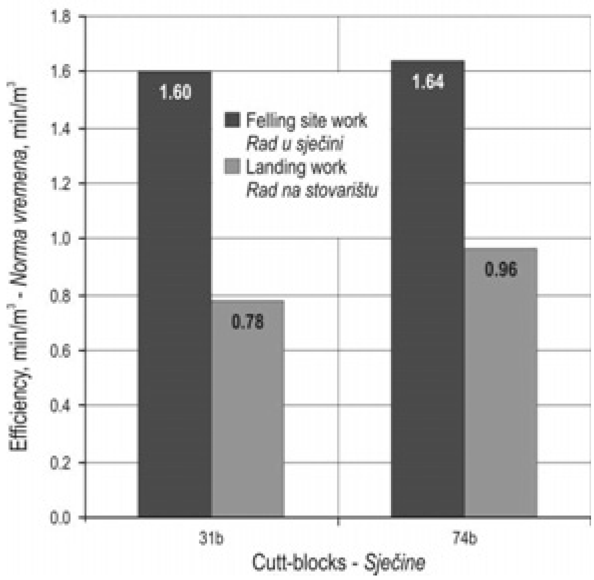


Figure 14 Terminal times consumption

Slika 14. *Utrošci fiksnih vremena* mostly affected by the number of felled trees per ha, i.e. the distance between the felled trees. The difference of 15.8 m^3/ha in felling density and the volume of mean felled trees (0.7 m^3/tree) between the involved workplaces, had no impact on time consumption of the skidder felling site work. This is also confirmed by approximately the same values of subcompartment openness (primary and secondary).

Narrow roadside landings lacking overview were the cause of higher time consumption of skidder work at workplace 74b than at workplace 31b, which was also confirmed by the difference test. Despite the absence of significance between the two investigated workplaces, the consumption of this group of work components will be taken as the mean value of both samples with the aim of achieving the best possible representative parameter of workplaces in the region of Gorski Kotar. Time consumption of the skidder felling site work calculated in this way is 6.95 ± 2.47 min/cycle (median 6.71 min/cycle) and time consumption of the roadside landing work is 3.71 ± 1.42 min/cycle (median 3.51 min/cycle).

7.6 Fuel consumption – *Potrošnja goriva*

Daily fuel consumption was measured by volume method, i.e. by reduction of oil volume in the skidder fuel tank. The average fuel consumption per operating hour ranged between 6.7 L/h (cutblock 31b) and 7.0 L/h (cutblock 74b). Fuel consumption per unit of extracted timber only ranged between 0.50 L/m^3 and 0.54 L/m^3.

7.7 Dependence of productivity and costs per unit on extraction distance – *Ovisnost proizvodnosti i jediničnih troškova rada traktora o udaljenosti privlačenja drva*

Skidder productivity and costs in timber skidding were calculated by use of the following expression

$$P=\frac{60}{k_{\mathrm{ALL}}\cdot\left[s_1\cdot\left(\frac{60}{v_1}+\frac{60}{v_2}\right)+s_2\cdot\left(\frac{60}{v_3}+\frac{60}{v_4}\right)+t_{\mathrm{L}}+t_{\mathrm{UNL}}\right]}\cdot V_{\mathrm{L}}\left[\frac{\mathrm{m}^3}{\mathrm{PMH}}\right]\text{ and } c=\frac{C}{P}\left[\frac{\mathrm{EUR}}{\mathrm{m}^3}\right]$$

By inserting the established parameters of the skidder performance in the above expressions, productivity was calculated as well as the skidder work cost per m^3 of the skidded timber depending on the skidding distance (Fig. 15). The distance of 50 m was considered for the skidder roadside landing travel.

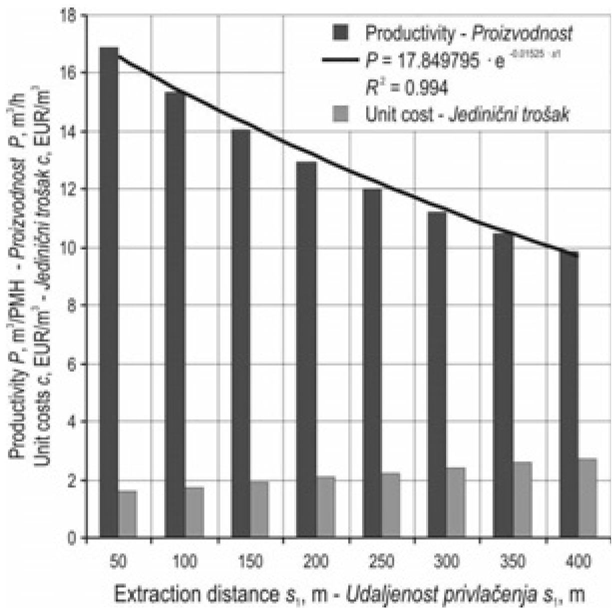


Figure 15 Productivity and cost per unit vs. skidding distance

Slika 15. *Ovisnost učinka i jediničnog troška o udaljenosti privlačenja drva*

Key – *Legenda*

	Measurement value – *Mjerna veličina*	Realised value *Ostvar. vrijednost*
P	Skidder productivity, m^3/PMH *Proizvodnost rada traktora*, m^3/h	16.9–9.9
s_1	Strip road extraction distance, km *Udaljenost privlačenja drva po traktorskom putu*, km	0.05–0.4
v_1	Speed of unloaded skidder on strip road, km/h *Brzina neopt. traktora po traktorskom putu*, km/h	5.33
v_2	Travel speed of loaded skidder on strip road, km/h *Brzina opt.traktora po traktorskom putu*, km/h	3.99
s_2	Roadside landing extraction distance, km *Udaljenost privlačenja drva po pom. stovarištu*, km	0.05
v_3	Travel speed of unloaded skidder on landing, km/h *Brzina neop. traktora po pomoćnom stovarištu*, km/h	8.77
v_4	Travel speed of loaded skidder on landing, km/h *Brzina opt. traktora po pomoćnom stovarištu*, km/h	4.69
t_L	Felling site time consumption, min/cycle *Vrijeme rada na sječini, min/tura*	6.95
t_{UNL}	Roadside landing time consumption, min/cycle *Vrijeme rada na pomoćnom stovarištu, min/tura*	3.71
k_{ALL}	Factor of allowance – *Faktor dodatnoga vremena*	1.205
V_L	Load volume, m^3/cycle – *Obujam tovara, m^3/tura*	4.4
C	Skidder rate (calculation), EUR/PMH *Trošak rada traktora (kalkulacija)*, EUR/h	26.89
c	Skidder cost per unit, EUR/m^3 *Jedinični trošak rada traktora*, EUR/m^3	1.6–2.7

For the researched range of data the dependence of the skidder productivity on the skidding distance is described by the exponential curve with the natural logarithm base with a complete correlation of variables.

For determining the skidder machine rate depending on its annual utilization, the calculations of machine costs were used, made by the Division of Forest Techniques of the Austrian Federal Forest Research Centre of the Federal Ministry of Agriculture Forestry Environment and Water Management (FBVA). Machine rate of Timberjack 240C according to the calculation based on 1,600 operating hours a year amounts to EUR 26.89 per PMH.

With skidding distance of 250 m (the average for the researched area), the possible productivity of Timberjack 240C under described work conditions is 12.0 m^3/PMH (5.0 min/m^3) with the skidding costs of EUR 2.2 per m^3.

Figure 16 Skidder rear protective board

Slika 16. *Nadogradnja stražnje zaštitne daske traktora*

8. Noticed disadvantages of skidder – *Uočeni nedostatci istraživanog traktora*

Due to the installation of a double drum winch, Konrad Adler HY 16, on the investigated vehicle, which is not regularly supplied by Timberjack as standard equipment on their skidders, in the course of the work, need arose for making some reconstructions and modifications:

- Rear protection board was enlarged on each side by 20 cm because log fronts kept striking the vehicle wheels (Fig. 16);
- Vertical rollers for adjusting the direction of the pulling cable were set too apart so that the cable could not be properly wound up on the drum. The vertical rollers were set closer by 210 mm on both drums;
- In winching load from sloped terrain, the cable used to come under the upper lead roller causing its break. A new upper roller was installed;
- Electro-hydraulic valves box of the winch was moved toward the central part of the vehicle because it touched the cabin when the skidder turned left;
- The settings for chokers were made on rear board;
- Winch drums are equipped with 16 mm cable and 14 mm cable is required in order to provide longer cable and to facilitate the work of hookers;
- The impossibility of checking the quantity and quality of cable winding on the drums from the cabin;

During their work, the skidder drivers noted some additional disadvantages:

- The front blade cannot be seen from the skidder cabin so that it should be enlarged on each side by 10 cm taking into consideration the load of its operating device.
- Installation is required of the indicator of oil level in the fuel tank, siren, inside rear-view mirror and the compressor for filling the air into pneumatic inner tubes.

9. Conclusions – *Zaključci*

The paper shows the results of research of extracting fir roundwood from the Croatian fir-beech forests by the skidder Timberjack 240C equipped with a double drum winch, Konrad Adler HY16. The research was carried out in the area of Delnice Forest Administration at two workplaces provided with the constructed network of strip roads with the density of about 100 m/ha. The workplaces differed in terms of the degree of terrain stoniness (no stoniness and stoniness ranging between 25 and 50 % of the area). The skidder productivity was determined by work and time study.

The paper also shows the results of some harvesting features of the investigated vehicle, such as: loaded and unloaded skidder travel speed on strip road and roadside landing, felling site and roadside landing time consumptions, allowance time, realized load volume, fuel consumption and the possible efficiency and unit costs of work depending on the skidding distance. The difference in terrain stoniness with the researched workplaces had no a considerable impact on any of the above skidder work parameters.

When moving on a strip road, the average speed of an unloaded skidder is 5.33 km/h and the average speed of a loaded skidder is by 25.1 % lower (3.99 km/h). When moving on a landing, the average speed of an unloaded skidder is 8.77 km/h and of the loaded skidder it is by 46.5 % lower (4.69 km/h).

The average time consumption of skidder felling site work (loading) is 6.95 ± 2.47 min/cycle and time consumption of skidder roadside landing work (unloading) is 3.71 ± 1.42 min/cycle.

Allowance time is 20.5 % of the effective time of the skidder work.

In skidding fir roundwood, the skidder realized an average load volume of 4.4 m^3/cycle consisting of 6 pieces of roundwood. The volume of an average piece of processed roundwood was 0.6 m^3 and it was 8 m in length.

The average fuel consumption was 6.9 litres per operating hour of the skidder or 0.52 L/m^3.

Possible productivity of Timberjack 240C is shown depending on timber skidding distance and it ranges between 16.9 m^3/h (50 m) and 9.9 m^3/h (400 m). According to the planning FBVA calculation of direct skidder work costs for the said range of skidding distances, the unit cost of timber skidding ranged between EUR 1.6 per m^3 and EUR 2.7 per m^3.

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Sažetak

Privlačenje jelove oblovine zglobnim traktorom Timberjack 240C iz gorskokotarskih prebornih sastojina

U radu su prikazani rezultati istraživanja privlačenja jelove oblovine u uvjetima dinarskih jelovo-bukovih šuma u Hrvatskoj zglobnim traktorom Timberjack 240C opremljenim dvobubanjskim vitlom Konrad Adler HY16. Istraživanja su provedena na području Uprave šuma Delnice na dva radilišta s izgrađenom mrežom traktorskih putova gustoće oko 100 m/ha. Radilišta su se međusobno razlikovala po stupnju kamenitosti terena (bez kamenitosti i kamenitosti 25 do 50 % površine). Proizvodnost je traktora utvrđena studijem rada i vremena.

Rad prikazuje rezultate nekih eksploatacijskih značajki istraživanoga vozila, kao što su: brzine kretanja neopterećenoga i opterećenoga traktora po traktorskom putu i pomoćnom stovarištu, utrošci vremena rada na sječini i pomoćnom stovarištu, dodatno vrijeme, ostvareni obujam tovara, potrošnja goriva te mogući učinci i jedinični troškovi rada ovisno o udaljenosti privlačenja drva. Razlika u kamenitosti istraživanih radilišta nije značajno utjecala ni na jedan od navedenih parametara rada traktora.

Pri kretanju po traktorskom putu prosječna brzina neopterećenoga traktora iznosi 5,33 km/h, dok je prosječna brzina opterećenoga traktora za 25,1 % manja (3,99 km/h). Pri kretanju po pomoćnom stovarištu utvrđena je prosječna brzina neopterećenoga traktora od 8,77 km/h, dok je kod opterećenoga ona za 46,5 % niža (4,69 km/h).

Prosječan utrošak vremena rada traktora na sječini iznosi 6,95 ± 2,47 min/tura, dok je utrošak vremena rada na pomoćnom stovarištu iznosio od 3,71 ± 1,42 min/tura.

Dodatno vrijeme iznosi 20,5 % efektivnoga vremena rada traktora.

Privlačeći jelovu oblovinu, traktor je ostvario prosječan obujam tovara od 4,4 m^3/tura koji se sastojao od 6 komada obloga drva. Prosječni komad izrađene oblovine imao je obujam od 0,6 m^3 te duljinu od 8 m.

Prosječna je potrošnja goriva iznosila 6,9 litara po pogonskom satu rada traktora, odnosno 0,52 L/m^3.

Moguća proizvodnost Timberjacka 240C prikazana je u ovisnosti o udaljenosti privlačenja drva te se kreće od 16,9 m^3/h (50 m) do 9,9 m^3/h (400 m). Prema planskoj FBVA kalkulaciji izravnih troškova rada traktora za navedeni raspon udaljenosti privlačenja jedinični se trošak privlačenja drva kretao od 1,6.EUR/m^3 do 2,7 EUR/m^3.

Ključne riječi: sekundarna otvorenost, Timberjack 240C, učinkovitost, jedinični trošak

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Received (*Primljeno*): November 29, 2004
Accepted (*Prihvaćeno*): March 8, 2005