Productivity factors of timberjack 1210 at forwarding the main felling roundwood in Croatian lowland forests

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PRODUCTIVITY FACTORS OF TIMBERJACK 1210 AT FORWARDING THE MAIN FELLING ROUNDWOOD IN CROATIAN LOWLAND FORESTS

ČIMBENICI PROIZVODNOSTI FORVARDERA TIMBERJACK 1210 PRI IZVOŽENJU OBLOGA DRVA GLAVNOGA PRIHODA HRVATSKIH NIZINSKIH ŠUMA

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The paper shows the influence of some factors (extraction distance, harvesting density, dimensions of processed roundwood, conditions of soil strenght, sorting of assortments during unloading) on productivity of 12-tones forwarder Timberjack 1210 which worked on extracting of roundwood from regeneration fellings in Croatian lowland forests.

Research was carried out on 5 workplaces at the period of 34 working days, when was extracted 3584 m^3 of hardwood assortments (oak and ash) in 370 forwarder cycles. The common feature of forwarder operation at all the researched felling sites was extraction of only technical roundwood processed by cut-to-lenght method with chainsaws, and free movement of the forwarder across the surface of felling units during the loading of timber. The sorting of assortments at the landing during unloading occurred in case of several types of species or quality classes of roundwood in the forwarder load. The felling sites differed by: average extraction distances (240 to 610 m), off-road soil strenght conditions in the course of the research (from mud to dry or frozen soil), harvesting density of the processed technical roundwood (85 to 132 m^3/ha) and the average quantity of the processed assortments: mid-diameter (23 to 51 cm), length (3.6 to 5.5 m), and volume (0.23 to 0.72 m^3/pcs).

The forwarder productivity was established by work and time study, and time consumptions of work components were measured by fly-back chronometry method.

The productivity level of forwarders per researched felling areas was influenced by the complex effects of off-road soil strenght conditions, dimensions of roundwood processed by cut-to-lenght method, harvesting density, and sorting of assortments at the landing during the unloading. For diversity and disparity of influenced factors encompassed at the research sites, their influence on the productivity of forwarders' operation was established indirectly,

through the time consumptions of work components, and the achieved load features. The research established the following:

– The load volume was under various influences of the key terrain factor of lowland forests – off-road soil strenght, as well as of the number of roundwood pieces of specific dimensions,

– The travel speed of unloaded and loaded forwarder depends on the type of surface on which the vehicle moves (off-road soil strenght conditions, forest road with gravel layer in the landing area),

– The time of work with crane at loading and unloading depends on the number of roundwood pieces of specific dimensions in the forwarder load,

– The time of works without crane at loading is influenced by the felling density of technical roundwood intended to primary timber transport,

–The time of works without crane at unloading depends on the need for timber sorting at the landing in case of occurrence of more types of species or quality classes of roundwood in the forwarder load,

–The allowance time depends on off-road soil strenght conditions.

Key words: forwarder productivity, influencing factors, regeneration fellings, Croatian lowland forests

INTRODUCTION
UVOD

Forestry mechinery 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 investigation of primary off-road transport of roundwood by forwarder Timberjack 1210. The purpose of this research is to give contribution to gaining knowledge of the productivity of a 12-ton forwarder Timberjack 1210 in extracting roundwood from regenerative felling in the Croatian lowland forests.

TIMBER FORWARDING
IZVOŽENJE DRVA

Forest harvesting, as the process of forest assortments production, consists of timber felling, processing and transport according to Krpan (1992). Transport of timber is broken down into

bunching, extracting and further transport. The term timber extraction, as part of timber transport, implies moving of trees or parts of trees (forest assortments) from the felling site (stump) to the landing.

When harvesting the Croatian lowland and hilly forests, timber forwarding is often used as a special form of timber extraction. In timber forwarding, the load is carried completely off the ground so that only the rolling resistance and inclination influence has to be overcome. Timber forwarding carried out by up-to-date mechanical means rely on a long-term traditional use of animal-drawn carts (Sever 1988). Today timber is forwarded by forwarders and tractors with (semi) trailer, the so called tractor equipages. The use of forwarders for extraction depends on the cut-to-length method of timber processing. Roundwood extracted by forwarders is long up to 6 (7) m. Apart from extracting, the forwarder can also be used for road hauling at shorter distances, thus excluding reloading at the roadside landing.

Tufts (1997) sets forth the following advantages of the use of the forwarder and cut-to-lenght method for timber processing: less damage to the residual stand, the ability to merchandise products in the woods, recovery of higher-valued products, reduces site damage, less visual impact on the residual stand, a smaller – more efficient workforce, and operator safety and comfort.

The forwarder productivity level is seriously affected by the following factors: timber extraction distance, tree species and dimensions of processed roundwood, felling density, terrain slope, surface obstacles, soil strength conditions, snow thickness, the openness of felling sites through a secondary network of forest roads, possible preliminary preparation of load by another means of work, need to sort the assortments at the roadside landing, skill of the operators as well as the technical and technological characteristics of the vehicle and loader (Richardson & Makkonen 1994, Poršinsky 1996, Krpan & Poršinsky 1997, Poršinsky 2000, Poršinsky 2001)

FORWARDER TIMBERJACK 1210

FORVARDER TIMBERJACK 1210

Forwarder Timberjack 1210 is a six-wheel drive vehicle, with bogie on the rear axle (Fig. 1). It is designed for off-road transport of roundwood as well as for the transport on constructed roads with the possibility of self-loading and unloading.

Timberjack 1210 belongs to the group of the latest development stage of traditional forwarders without the latest achievements of independent wheels with the device for leveling the whole vehicle or only the cabin. The entire forwarder control – control of driving, engine, gearbox, hydraulic crane, is carried out by the so-called proportional technique by use of joysticks in the handholds of the driver's seat. Along with electro-hydraulic distributors used by forwarders before, hydrostatic-mechanical transmission is one of the latest components to provide it.

Figure 1. Forwarder Timberjack 1210
Slika 1. Forvarder Timberjack 1210

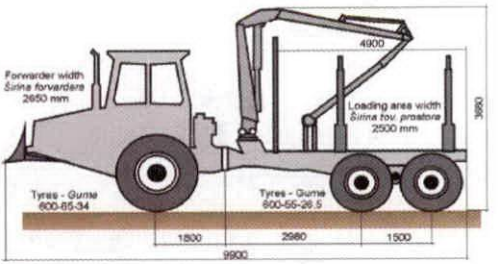

Figure 2. Basic dimensions
Slika 2. Osnovne dimenzije

The basic characteristics of the forwarder Timberjack 1210 are as follows:

- Perkins 1006-6TW engine is a water-cooled, 6-cyliner, diesel engine with turbo charger, which generates a power output of 114 kW at 2200 min^{-1} and 511 Nm of torque at 1590 min^{-1},
- Steering is articulated with maximum angle of ±40° and the turning radius 8.7 m,
- Forwarder dimensions are shown schematically in Figure 2. The mass of unloaded forwarder is the same as its permited load rating – 12,000 kg,
- Hydraulic loader is a Loglift F 70 L 71 model used for loading and unloading timber assortments. The crane has a lifting moment of 70 kNm (66.2 kNm is an average) and a maximum 7.1 m reach. By checking the lifting moment of the loader based on measurements (Horvat & Sever 1995), the following deviations from manufacturer's specifications have been determined: the crane also has the fourth (extension) arm so that its highest reach is 9.25 m and the mean lifting moment of the loader is by 35 % lower than specified and it is 42.7 kNm.

SCOPE OF RESEARCH
CILJ ISTRAŽIVANJA

The scope of research is to establish the factors affecting the work productivity of the forwarder Timberjack 1210 engaged in extracting roundwood from regeneration felling in the Croatian lowland forests.

Timber extraction by forwarders has the characteristics of cyclic work. Each forwarder cycle consists of four basic groups of cyclic working components (unloaded travel from landing to first loading point, felling site works – loading, loaded travel from felling site to landing, landing works – unloading) and work breaks (delay times) i.e. time consumption of random character. This means that by reducing the consumption of total cycle time and by increasing the load volume better forwarder productivity is achieved. Forwarder productivity, i.e. total cycle time and load volume, is affected by a large number of factors, among which this research will cover the following: extraction distance, felling density, dimensions of processed roundwood, soil strength conditions and sorting of assortments in unloading.

In addition to establishing these factors, the way and extent of their impact on the productivity of roundwood extraction will also be determined. By use of computer processing involving suitable statistical methods, interrelationship between the achieved productivities and the influencing factors will be determined.

The obtained results of research should be the base for the assessment of the use of the tested vehicle for timber extraction in set operating conditions.

METHOD OF RESEARCH AND DATA ANALYSIS
METODA ISTRAŽIVANJA I OBRADA PODATAKA

Forwarder performance was investigated by time and work study method. The time used for timber extraction was divided into work components (Fig. 3) 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.

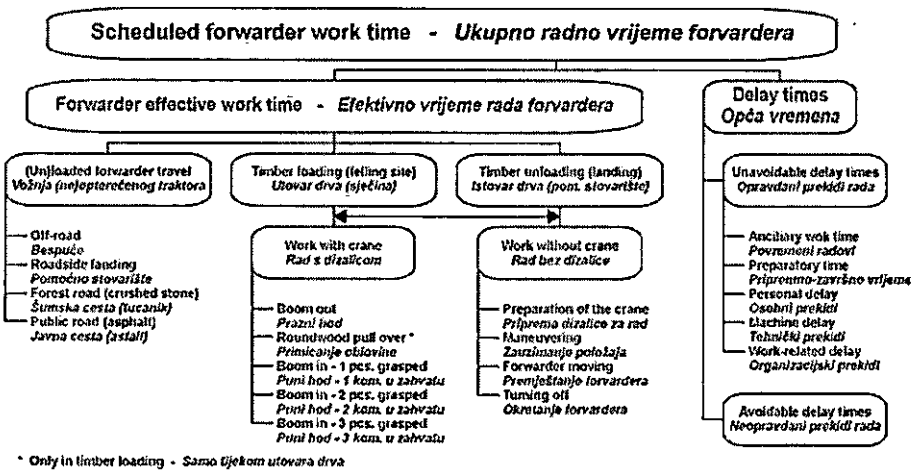

Figure 3. Working components
Slika 3. Radne sastavnice

Distances of unloaded and loaded travel were measured by the measuring tape and load related data were collected by measuring the mid diameter and length of each piece of roundwood. Soil strength (soil condition) on which the forwarder was moving during research was not measured with adequate measuring equipment. It was described instead (frozen soil, partly frozen, dry, moist, wet, muddy, waterlogged) with the aim of breaking it down subsequently into two classes of soil strength: good soil strength and limited soil strength.

Due to the variety and complexness of factors affecting the productivity of forwarder performance, the analysis will determine their impact on forwarder productivity indirectly through researched time consumptions and load characteristics (Samset 1988, Thompson

1992). This would be the way to connect the impact of one factor (or group of factors) with time consumption of specific working components and load characteristics, respectively. The basic unit of analysis would be the forwarder cycle.

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.

With independent variables, different measures of the central dispersion tendency of measurement data were studied and median and arithmetical mean value were chosen as the

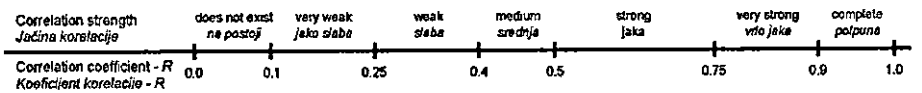

Figure 4. Roemer-Orphals scale
Slika 4. Roemer-Orphalova raspodjela

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 (Fig. 4).

RESEARCH SITES
MJESTA ISTRAŽIVANJA

Research of productivity of timber extraction by forwarder Timberjack 1210 was carried out at five different felling sites: Otok, Gradiška, Gorica 1, Čazma, Gorica 2 (Fig. 5).

Figure 5. Research sites
Slika 5. Mjesta istraživanja

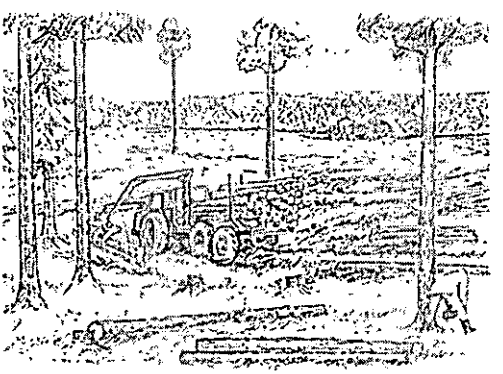

Figure 6. Applied technology (Malmberg 1990)
Slika 6. Primijenjena tehnologija (Malmberg 1990)

Different stand and harvesting conditions were found at each researched felling site and they are summarized and shown comparatively in Table 1.

Table 1. Exploatation stand features
Tablica 1. Eksploatacijske značajke sastojina

Felling sites - Sječina	Otok	Gradiška	Gorica 1	Čazma	Gorica 2
Forest office - *Šumarija*	Otok	Nova Gradiška	Velika Gorica	Čazma	Velika Gorica
Management unit - *Gospodarska jedinica*	Slavir	Gradiška brda	Šilj. dubrava II	Čaz. nizin. šume	Šilj. dubrava II
Subcompartment - *Odsjek*	57a	23c	46b	11d	139a
Age, years - *Starost, godine*	132	75	145	111	135
Rotation, years - *Ophodnja, godine*	120	80	120	120	140
Area - *Površina*, ha	56.07	19.8	15.32	12.63	20.29
Extraction distance - Udaljenost privlačenja, m	400	950	240	280	240
Growing stock - *Drvna zaliha*, m³/ha	484	268	249	384	346
Basal area - *Temeljnica*, m²/ha	26.6	23.0	16.9	25.2	23.7
Trees per ha - *Stabala po ha*	143	474	46	253	180
Management class - Uređajni razred	oak from seed*	coppice of oak**	oak from seed*	oak from seed*	oak from seed*
	lužnjak iz sjemena	panjača kitnjaka	*lužnjak iz sjemena*	*lužnjak iz sjemena*	*lužnjak iz sjemena*
Silvicurtural type - *Uzgojni oblik*	high - *visoki*	low - *niski*	high - *visoki*	high - *visoki*	high - *visoki*
Felling type - *Vrsta sijeka*	Seeding - *Naplodni*	Seeding - *Naplodni*	Final - *Dovršni*	Final - *Dovršni*	Final - *Dovršni*
Harvesting density - Sječna gustoća, m³/ha	186	186	227	236	206
Mean cutting tree - Srednje sječno stablo, m³	4.3	0.6	5.4	5.1	4.2
Soil conditions - *Stanje tla*	frosen - *smrznuto*	moist - *vlažno*	woterlogged - *blatno*	dry - *suho*	woterlogged - *blatno*

* *Quercus robur* L. , ** *Quercus petrea* (Matt.) Liebl. & *Quercus cerris* L.

Common features for all researched felling sites are as follows:

- each researched felling sites was in the period of natural regeneration by shelterwood system,
- motor-manual felling of trees and cut-to-length method for processing assortments by chain saws and processed roundwood extracted by use of forwarders (Fig. 6),
- researched felling sites make part of lowland forests without the impact of slopes,
- forest soils of the researched felling sites make part of the group of hydromorfic, alluvial coherent soils (different types of gley), whose characteristic is their changeable bearing capacity depending on the current soil moisture content,
- extraction only of technical roundwood (veneer bolts, sawlogs and small-sized technical roundwood) from felling units, while cordwood (fuelwood) was to be processed by local inhabitants. Due to such approach, the parameter affecting the forwarder productivity is the felling density of

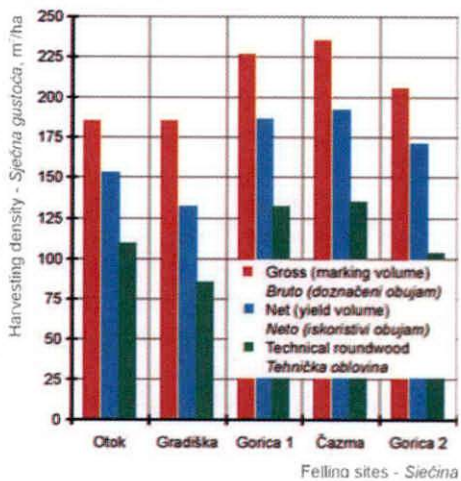

Figure 7. Harvesting density
Slika 7. Sječna gustoća

technical roundwood (Fig. 7),
- when working in the felling units (loading the tractor and unloaded and loaded travel of the tractor) the forwarder could move freely within the area of the felling site as there was no network of secondary forest roads and no bunching of processed assortments was carried out,
- in the event of several species and quality classes of timber in the forwarder loading area, sorting of roundwood in separate piles was carried out at roadside landing.

METHOD OF FORWARDER OPERATION
NAČIN RADA FORVARDERA

At the beginning of the working day, drivers would prepare the vehicle for the work. At the end of unloaded travel on the landing the forwarder would cross over the forest road drainage canal and continue its off-road travel on the felling site to the place of first loading. After loading the logs within the reach of the loader, the forwarder would go on with its travel on the felling site (maneuvering, positioning) to the place of its next loading. In this way, the driver would repeat the operations until the optimum load was loaded depending on soil strength conditions. After having completed the loading operation, the forwarder would start its loaded travel toward the roadside landing. At this landing, situated by the forest road, passing on the boundary of the sub-compartment, during unloading, the logs would be sorted by tree species and quality classes. After finishing the operations at the roadside landing, a new cycle would begin. At the end of the working day, the drivers would check the tractor to eliminate possible faults and they would clean and lubricate it.

RESULTS OF RESEARCH
REZULTATI ISTRAŽIVANJA

Research of timber extraction by forwarder Timberjack 1210 at the workplaces is shown through achieved results such as: load parameters, structure of total and effective time, structure of delay times and allowance time, forwarder travel speed and work time consumptions at the felling site and roadside landing. In the same way, possible productivities are shown depending on timber extraction distance and other factors affecting timber extraction.

REALISED PRODUCTIVITY AND STRUCTURE OF TOTAL AND EFFECTIVE TIME
OSTVARENI UČINAK TE STRUKTURA UKUPNO UTROŠENOGA I EFEKTIVNOGA VREMENA

Forwarder performance was being observed at all five workplaces for 34 working days. During that time 3,584 m^3 of timber was extracted in 370 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 2. The variety of factors affecting research at felling sites caused considerable differences between realized average

productivities. The lowest realized productivity was recorded at the felling site Gradiška (6.6 m³/h), followed by Čazma (11.2 m³/h), Gorica 1 (13.1 m³/h), Gorica 2 (18.8 m³/h) and finally Otok (19.2 m³/h). Similarly to the realized average productivities, considerable differences were observed between researched felling sites with regard to total time consumptions (from 3.13 min/m³ to 9.07 min/m³) and effective time consumptions (from 2.21 min/m³ to 7.25 min/m³) per unit of extracted timber.

The difference of 290 % between the minimum and maximum realized average productivity lies in the difference between working conditions at various workplaces. The average distance of timber extraction ranged between 135 m and 610 m, the average load volume was from 7.3 m³ to 12.2 m³, the average volume of processed roundwood was from 0.23 m³ to 0.72 m³, felling density of technical roundwood was from 85 m³/ha to 135 m³/ha and soil strength conditions ranged from muddy to frozen (dry) soil.

Table 2. Structure of total time consumption and some realised average values
Tablica 2. Struktura ukupno utrošenih vremena i neke ostvarene prosječne vrijednosti

Work components – *Radne sastavnice*	Felling sites – Sječine				
	Otok	Gradiška	Gorica 1	Čazma	Gorica 2
	Time consumptions – *Utrošci vremena*, min				
Unloaded forwarder travel – Vožnja neopterećenoga traktora	344.53	684.33	479.66	498.62	286.05
Off-road – Bespuće	293.42	455.83	282.58	426.27	164.49
Roadside landing – Pomoćno stovarište	46.13	19.09	25.22	72.35	36.45
Forest road – *Šumska cesta*	4.98	166.45	–	–	68.36
Public road (asphalt) – *Javna cesta (asfalt)*	–	42.96	171.86	–	16.75
Timber loading (felling site) – Utovar drva (sječina)	1022.29	876.00	642.56	652.68	657.76
Work with crane – *Rad s dizalicom*	690.79	600.94	410.76	417.83	420.65
Work without crane – *Rad bez dizalice*	331.50	275.06	231.80	234.85	237.11
Loaded forwarder travel – Vožnja opterećenog traktora	432.59	686.96	404.57	736.36	339.81
Off-road - Bespuće	387.38	586.19	374.24	659.49	290.29
Roadside landing – Pomoćno stovarište	45.21	22.5	30.33	76.87	43.37
Forest road – *Šumska cesta*	–	65.91	–	–	6.15
Public road (asphalt) – *Javna cesta (asfalt)*	–	12.36	–	–	–
Timber unloading (roadside landing) – Istovar drva (pomoćno stovarište)	694.86	344.27	369.65	374.80	383.24
Work with crane – *Rad s dizalicom*	563.86	263.53	316.5	332.22	322.70
Work without crane – *Rad bez dizalice*	131.00	80.74	53.15	42.58	60.54
Effective time – *Efektivno vrijeme*	2494.27	2591.56	1896.44	2262.46	1666.86
Delay time – Opća vremena	1043.02	651.89	1663.78	998.03	602.87
Total time – *Ukupno utrošeno vrijeme*	3537.29	3243.45	3560.22	3260.49	2269.73
Ratio Delay time / Effective time – Odnos općega i efektivnoga vremena	0.42	0.25	0.88	0.44	0.36
Effective time per unit – *Efektivno vrijeme po jedinici*, min/m³	2.21	7.25	2.44	3.73	2.34
Total time per unit – *Ukupno vrijeme po jedinici*, min/m³	3.13	9.07	4.57	5.38	3.19
Realised productivity – *Ostvarena proizvodnost*, m³/h	19.2	6.6	13.1	11.2	18.8
Average extraction distance – Prosječna udaljenost privlačenja, m	310	505	135	610	190
Average volume of load, m³/cycle – Prosječni obujam tovara, m³/tura	12.2	9.2	7.3	9.6	10.5
Average volume of roundwood, m³/pcs – Prosječni obujam oblovine, m³/kom.	0.60	0.23	0.72	0.67	0.60
Days of observation – *Broj dana snimanja*	7	8	10	5	4
Number of cycles – *Snimljeno turnusa*	93	39	107	63	68
Total forwarded volume – *Ukupno izvezeno drvo*, m³	1130.6	357.6	778.5	606.1	711.2
Forwarded pieces of roundwood – *Izvezeno komada oblovine*	1855	1547	1079	912	1191

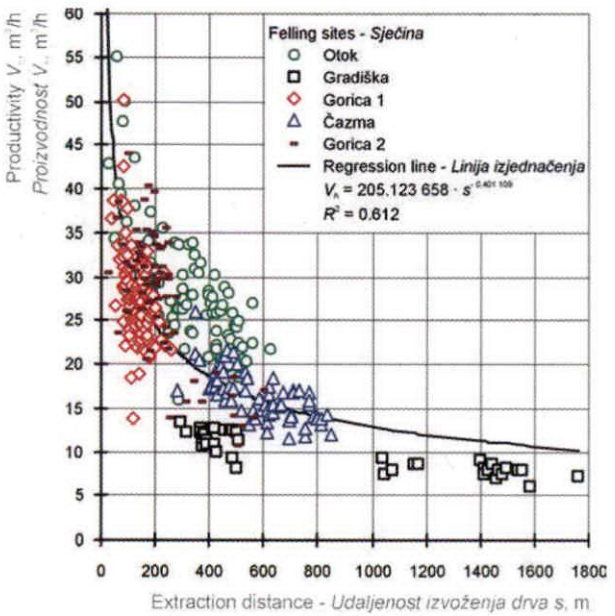

Figure 8. Productivity vs. extraction distance
Slika 8. Ovisnost proizvodnosti o udaljenosti privlačenja

Effective time accounts for 53.3 % (Gorica 1) to 79.9 % (Gradiška) of total time. The reason for such a large range of share of the effective time in total time, lies in different levels of quality of work organization at different research sites as well as in difficulties met during research in timber extraction depending on terrain conditions at different workplaces. During research, delay times accounted for 20.1 % (Gradiška) to 46.7 % (Gorica 1) of total time consumption.

By excluding recorded delay times (with different shares at each researched felling site) a clearer picture can be seen of the variability of forwarder productivity depending on factors affecting specific felling sites during research. The productivity per effective hour of work (Fig. 8) was calculated out of data related to effective time consumptions and load volumes of each recorded cycle at all researched felling sites.

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 technological 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, Krpan and Ivanović 1994).

Shares of avoidable or unavoidable delay times within the achieved delay times are shown in Figure 9 and Table 3 shows the structure of allowance time that ranged between 18 % and 24 % of effective time at researched felling sites. Analyzing the shares of allowance time component groups related to soil

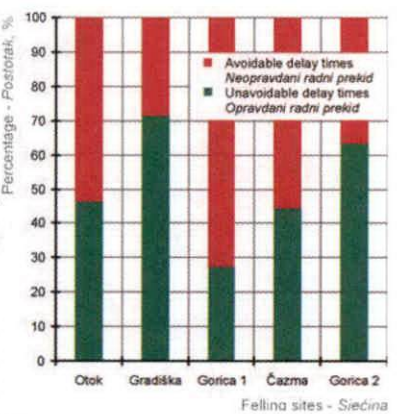

Figure 9. Structure of delay times
Slika 9. Struktura općih vremena

condition, considerable increase of share of ancillary works can be noticed in case of limited soil strength while the deviations with other components are not significant.

Table 3. Structure of allowance time
Tablica 3. Struktura dodatnoga vremena

Unavoidable delay times *Opravdani prekidi rada*	Good soil strenght conditions *Tlo dobre nosivosti*			Limited soil strenght conditions *Tlo ograničene nosivosti*		Average soil strenght conditions *Prosječno uvjeti nosivosti tla*	
	Gradiška	Otok	Čazma	Gorica 1	Gorica 2	good - *dobri*	limited - ograničeni
	% of effective time - *% od efektivnog vremena*						
Ancillary work time *Povremeni radovi*	3.30	4.57	4.00	8.47	8.05	3.96	8.47
Preparatory time *Pripremno-završno vrijeme*	3.58	3.98	4.16	4.24	4.38	4.07	4.07
Personal delay *Osobni prekidi*	9.55	9.82	9.77	10.12	9.66	9.78	9.78
Machine delay *Tehnički prekidi*	0.52	1.03	0.90	1.21	0.24	0.78	0.78
Work related delay *Organizacijski prekidi*	1.04	0.00	0.74	0.00	0.60	0.48	0.48
Allowance time *Dodatno vrijeme*	18.0	19.4	19.6	24.0	22.9	19.1	23.6

The allowance time is, therefore, modeled on the basis of soil strength conditions. The average share was taken for the component groups: preparatory times, personal delays, delays related to means of work and work organization, regardless of soil strength conditions and for ancillary works the average share was taken with respect to soil strength conditions. The modeled allowance time for good soil strength is 19.1 % of effective time and with soil of limited strength it is by 4.5 % higher.

FEATURES OF LOAD
ZNAČAJKE TOVARA

Load volume is the parameter that affects directly the forwarder productivity level. Maximum load rating for forwarder Timberjack 1210 is 12,000 kg, which is approximately 11 m^3 of roundwood made of hardwood timber in raw condition (density ~ 1.1 t/m^3). Table 4 shows the data on realized load volumes, number of roundwood pieces in the load and dimensions of extracted roundwood by researched felling site. Figure 11 shows these values depending on soil strength conditions and dimensions of roundwood.

In general the most suitable soil for extraction timber by forwarders is the frozen or dry soil condition, where forest off-road mobility of the forwarder becomes prominent (Sever and Slabak 1988). By increase of water content (moisture), especially in gley soils, they come into a limited strength condition and then forwarder mobility becomes limited or even doubtful (Horvat and Poršinsky 2000). These restrictions are shown in wheel slipping, reduction of load volume and travel speed, disturbed vehicle stability and also serious damage to soil (Krpan et al. 1993, Horvat 1995, Martinić 2000).

Figure 10. Forwarder load
Slika 10. Tovar forvardera

In general the most suitable soil for extraction timber by forwarders is the frozen or dry soil condition, where forest off-road mobility of the forwarder becomes prominent (Sever and Slabak 1988). By increase of water content (moisture), especially in gley soils, they come into a limited strength condition and then forwarder mobility becomes limited or even doubtful (Horvat and Poršinsky 2000). These restrictions are shown in wheel slipping, reduction of load volume and travel speed, disturbed vehicle stability and also serious damage to soil (Krpan *et al.* 1993, Horvat 1995, Martinić 2000).

On soils of good strength (frozen, dry to partly moist soil condition) the load volume averaged 10.7 ± 1.8 m³/cycle, and it ranged between 7.1 m³ and 14.1 m³, and on soils of limited strength (moist to muddy soil condition) the average realized load volume was 8.5 ± 1.9 m³/cycle, ranging between 3.3 m³ and 13.9 m³. The wide range of realized values is the result of the drivers efforts to extract the largest possible load volume per cycle at the price of travel speed and tractor's stability as well as extreme damage to the soil. As a result, drivers very often used to overload the vehicle (load volumes exceeding 11 m³/cycle).

Table 4. Load parameters
Tablica 4 Značajke tovara

Felling sites *Sječina*	Load volume *Obujam tovara*	No. of pcs. in the load *Komada u tovaru*	Quantity of roundwood - Veličina oblovine		
			diameter - *promjer*	length - *duljina*	volume - *obujam*
	m³/cycle - m³/tura	pcs/cycle – kom./tura	cm	m	m³/pcs – m³/kom.
Otok	12.2 ± 1.1 (9.9 – 14.1)*	20 ± 3.5 (12 - 29)*	43 ± 9 (25 - 89)*	4.0 ± 1.0 (2.0 - 7.9)*	0.60 ± 0.31 (0.15 - 2.55)*
Gradiška	9.2 ± 0.8 (7.6 - 11.3)*	40 ± 4.3 (30 - 48)*	23 ± 5 (12 - 45)*	5.5 ± 1.0 (2.0 - 9.0)*	0.23 ± 0.09 (0.06 - 0.55)*
Gorica 1	7.3 ± 1.1 (3.3 - 9.9)*	10 ± 2.2 (5 - 18)*	51 ± 10 (25 - 80)*	3.4 ± 0.8 (2.0 - 6.5)*	0.72 ± 0.31 (0.17 - 1.86)*
Čazma	9.6 ± 1.3 (7.1 - 12.4)*	14 ± 2.2 (8 - 19)*	44 ± 10 (25 - 76)*	4.2 ± 1.2 (2.0 - 8.4)*	0.67 ± 0.34 (0.12 - 2.11)*
Gorica 2	10.5 ± 1.2 (8.0 - 13.9)*	18 ± 2.9 (12 - 23)*	45 ± 9 (26 - 79)*	3.6 ± 0.8 (2.0 - 6.1)*	0.60 ± 0.29 (0.13 - 2.04)*

* Minimums and maximums - *Najmanja i najveća izmjera*

On soils of good strength (frozen, dry to partly moist soil condition) the load volume averaged 10.7 ± 1.8 m³/cycle, and it ranged between 7.1 m³ and 14.1 m³, and on soils of limited strength (moist to muddy soil condition) the average realized load volume was 8.5 ± 1.9 m³/

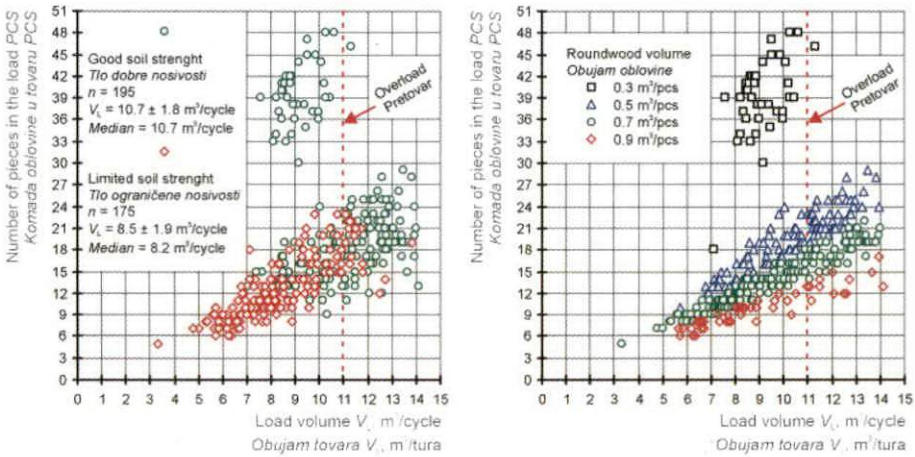

Figure 11. Load volume vs. soil conditions and roundwood volume

Slika 11. Ovisnost obujma tovara o nosivosti tla i obujmu oblovine

cycle, ranging between 3.3 m^3 and 13.9 m^3. The wide range of realized values is the result of the drivers efforts to extract the largest possible load volume per cycle at the price of travel speed and tractor's stability as well as extreme damage to the soil. As a result, drivers very often used to overload the vehicle (load volumes exceeding 11 m^3/cycle).

Apart from the impact of terrain factors (Mellgren 1980, Berg 1992), which mostly reduce the forwarder load volume, it also depends on the number of roundwood pieces of specific dimensions. Mid diameters of assortments range between 12 cm and 89 cm, length 2 m to 9 m and volume 0.06 m^3 to 2.55 m^3. Such a wide range of dimensions of individual pieces of processed roundwood at researched felling sites is the result of cut-to-length metod in timber processing as well as of different dimensions of marked and felled trees at felling sites involved by regeneration felling.

Due to different dimensions (mid diameter and length) between assortments transported within the forwarder load, the average piece volume is used further on as the parameter representing the mean assortment in the vehicle load area (Conway 1984).

The data of load features (number and average piece volume), within the limit values of 95 % probability of arithmetic mean interval estimate of load volume depending on soil

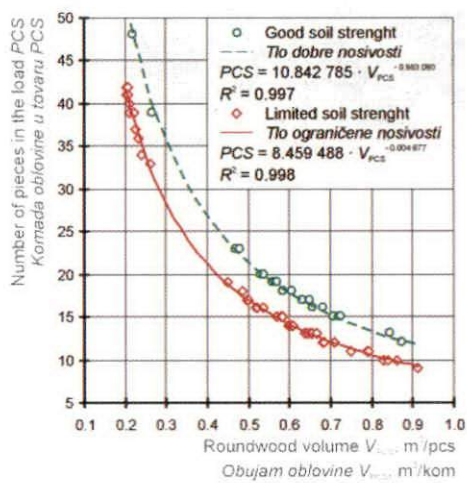

Figure 12. Load volume vs. no. and volume of roundwood

Slika 12. Ovisnost obujma tovara o broju komada i obujmu oblovine

strength conditions, are regressed by exponential equation with complete correlation of variables (Fig. 12). In this way the dependence of the number of pieces and volume of roundwood in the load was calculated depending on soil strength conditions, which will be necessary for modeling algorithms of crane time consumptions in (un)loading timber.

FORWARDER TRAVEL TIMES
VREMENA KRETANJA FORVARDERA

Travel time consumptions of unloaded and loaded forwarder 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, public road with asphalt cover). Travel times of loaded vehicles will be investigated versus load volume.

TIME CONSUMPTIONS AND TRAVEL SPEEDS OF FORWARDER ON OFF-ROAD
UTROŠCI VREMENA I BRZINE KRETANJA FORVARDERA PO ŠUMSKOM BESPUĆU

At researched felling sites, soil strenght condition (Fig. 13 and 14) is the only terrain factor affecting forwarder mobility on forest off-road terrain. Loaded tractor travel is also affected by the volume of the load extracted by forwarder.

Figure 13. Limited soil strenght
Slika 13. Tlo ograničene nosivosti

Figure 14. Good soil strenght
Slika 14. Tlo dobre nosivosti

The impact of soil strength condition on travel time consumption of unloaded forwarder is shown in Figure 15 and Figure 16 shows the travel of loaded forwarder.

The data on travel time consumption of (un)loaded forwarder depending on travel distance are regressed with straight line from origin for both soil strength conditions.

For unloaded forwarder travel on limited soil strength a very strong correlation was obtained ($R = 0.825$), while for unloaded forwarder travel on good soil strength a complete correlation was obtained ($R = 0.973$). The average travel speed of unloaded forwarder on good soil strength is 4.6 km/h and on limited soil strength it is by 24 % lower (3.5 km/h).

By regressing the data on travel time consumption of loaded forwarder (Fig. 16) a complete correlation was obtained for both classes of soil strenght condition. The average travel speed of

loaded forwarder on good soil strength is 3.2 km/h and on limited soil strength by 25 % lower (2.4 km/h).

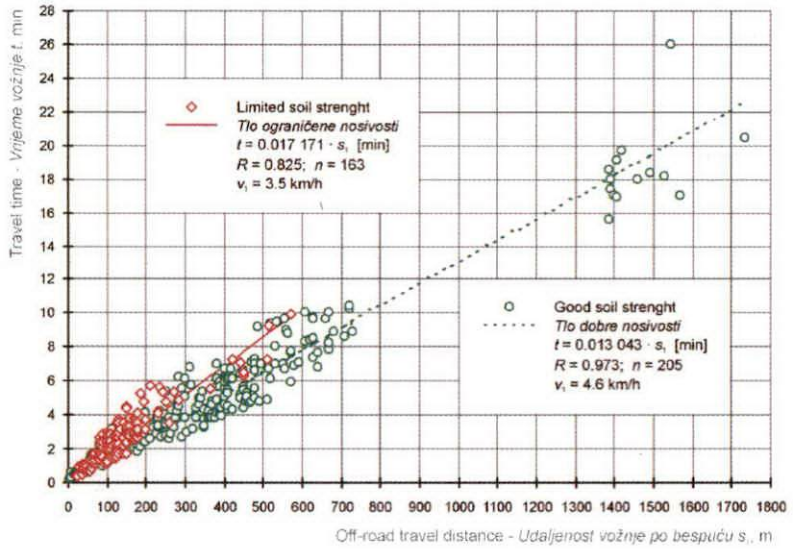

Figure 15. Unloaded forwarder (soil strenght conditions)
Slika 15. Neopterećeni forvarder (uvjeti nosivosti tla)

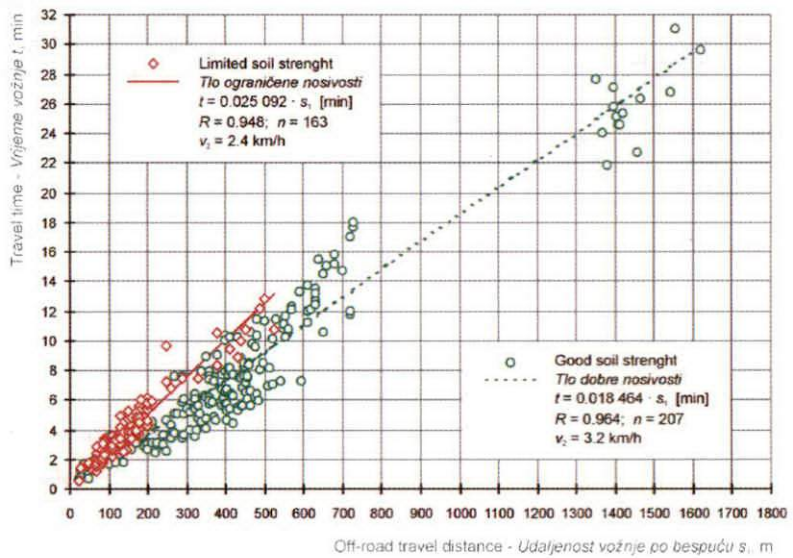

Figure 16. Loaded forwarder (soil strenght conditions)
Slika 16. Opterećeni forvarder (uvjeti nosivosti tla)

The impact of load volume on travel time consumption of loaded forwarder is shown in Figure 17, by classes of load volume (6 m³/cycle, 8 m³/cycle, 10 m³/cycle and 12 m³/cycle). Due to mixing of data on travel time consumption of different classes of load volume within a huge number of data, it can be concluded that the load volume has no impact on travel time consumption of the loaded forwarder Timberjack 1210, probably because of its technical characteristics.

On good strength soils the average travel speed of a loaded forwarder is by 30 % lower than the average speed of unloaded tractor and on limited strength soil it is lower by 31 %.

It can be concluded, that time consumption and average travel speeds of (un)loaded forwarder Timberjack 1210 on forest off-road terrain are only affected by soil conditions, while the impact of load volume on loaded tractor travel is reduced by technical characteristics of forwarder itself.

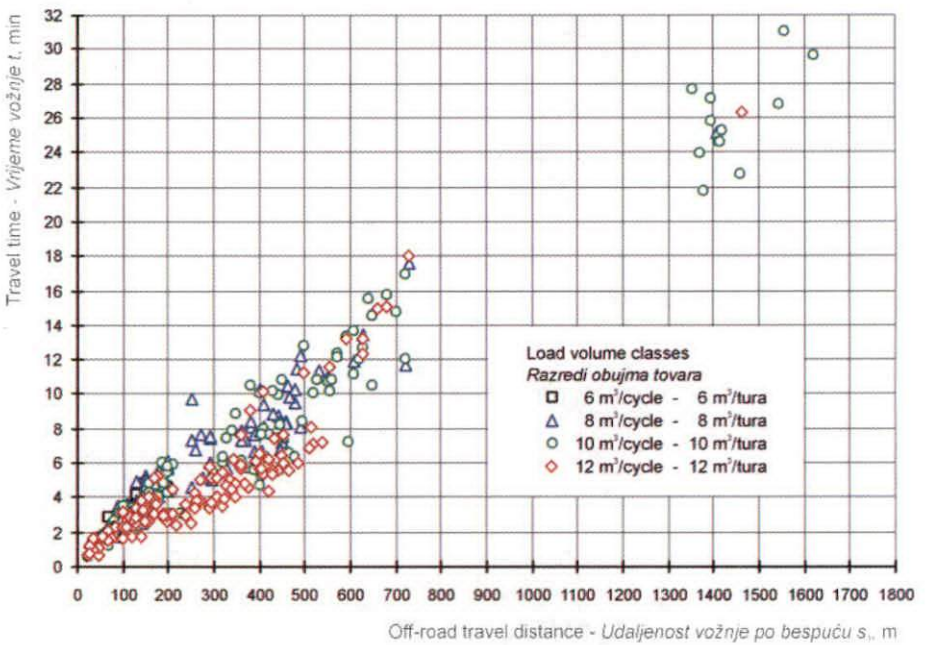

Figure 17. Loaded forwarder (load volume classess)
Slika 17. Opterećeni forvarder (razredi obujma tovara)

TIME CONSUMPTIONS AND TRAVEL SPEEDS OF FORWARDER ON THE CONSTRUCTED ROADS

UTROŠCI VREMENA I BRZINE KRETANJA FORVARDERA PO IZGRAĐENIM PUTOVIMA

With regard to the type of the upper layer of constructed roads, forwarder travel is separated into travel on forest road with crushed stone cover and travel on public road with asphalt cover.

Forwarder travel on forest road with crushed stone cover is additionally separated into vehicle travel in the area of roadside landing and outside of it (Fig. 18).

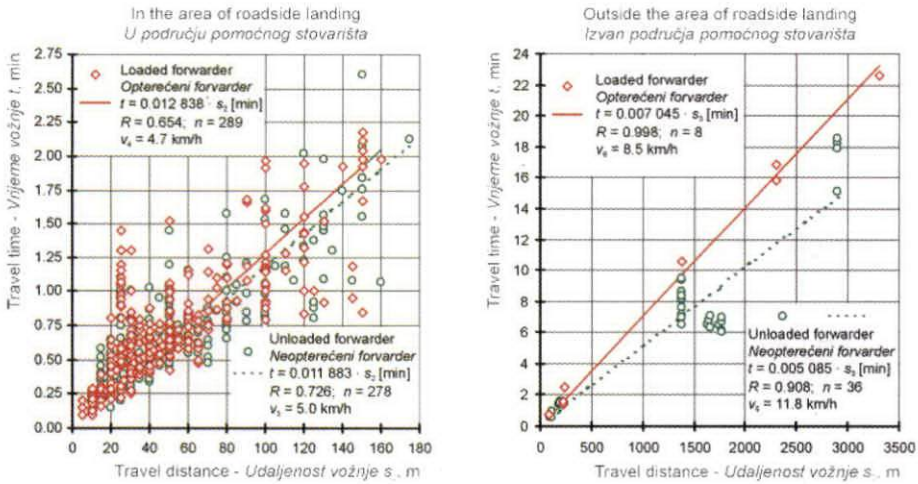

Figure 18. Forest road (crushed stone)
Slika 18. Šumska cesta (tucanički zastor)

The reason for this separation lies in a series of roadside landing characteristics (the road gets narrower due to piles of timber on both sides of forest road and to the presence of other means of work of primary and secondary timber transport with occasional occurence of a series of other forestry activities related to roadside landings), which affect forwarder traficability in their area, as well as in the necessity of this working component in each tractor cycle, while all other forwarder moving on constructed forest roads occurred exclusively within the vehicle arrival on and departure from the workplace. The above characteristics of roadside landings caused high dispersions and mixing of measured travel time consumptions of (un)loaded forwarder depending on travel distance. The average travel speed of unloaded forwarder in the area of roadside landing is 5 km/h and with loaded forwarder it is by 6 % lower (4.7 km/h).

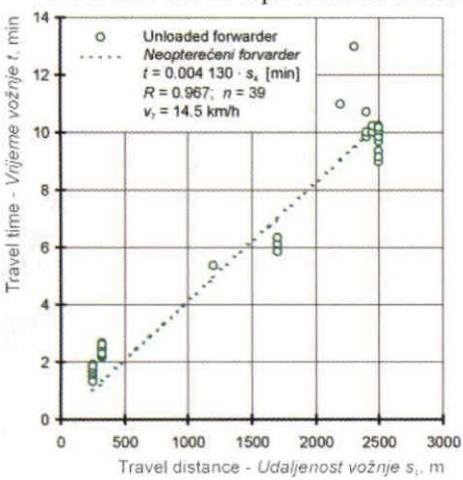

Figure 19. Public road (asphalt)
Slika 19. Javna cesta (asfalt)

Higher travel speeds were achieved when the forwarder travelled on forest road outside the area of roadside landing and they were as follows: 11.8 km/h for unloaded vehicle and 8.5 km/h for the loaded one.

During research, forwarder travel on public road with asphalt cover was only realized for unloaded vehicle at the distance of up to 2500 m with the average speed of 14.5 km/h (Fig. 19).

TIME CONSUMPTIONS OF TIMBER (UN)LOADING
UTROŠCI VREMENA UTOVARA I ISTOVARA DRVA

At researched felling sites, time consumptions of forwarder work at the felling site and roadside landing ranged widely between 9.46 min/cycle and 31.29 min/cycle or from 1.30 min/m³ to 3.40 min/m³ per unit of extracted timber. In loading and unloading timber, the drivers most frequently used to grasp one (rarely two) pieces of roundwood by the hydraulic crane, except at Gradiška felling site, where the driver used to grasp two and even three pieces by the crane graple at one boom in during at unloading.

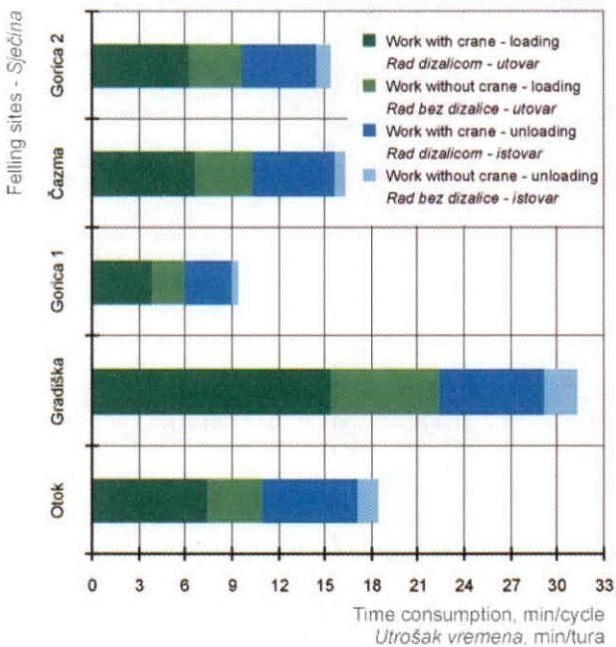

Figure 20. Time consumptions of timber (un)loading
Slika 20. Utrošci vremena utovara i istovara drva

In order to provide cross reference with some other influencing factors, time consumptions of forwarder work at the felling site and roadside landing were separated into four groups of working components (Table 5).

The base for this separation is the workplace (felling site and roadside landing) and the type of work carried out by the vehicle (work with the crane or without the crane – vehicle moving).

Table 5. Analysis of time consumptions of loading and unloading
Tablica 5. Analiza utrošaka vremena utovara i istovara drva

Work components *Radne sastavnice*	Felling sites - Sječina				
	Otok	Gradiška	Gorica 1	Čazma	Gorica 2
	Time consumption - *Utrošak vremena*, min				
Timber loading (feling site) Utovar drva (sječina)	10.99 ± 2.05 (6.61 - 16.64)*	22.46 ± 3.40 (16.16 - 31.34)*	6.01 ± 1.40 (3.53 - 10.16)*	10.36 ± 2.52 (5.88 - 20.74)*	9.67 ± 1.78 (6.50 - 16.37)*
Work with crane *Rad s dizalicom*	7.43 ± 1.40 (4.81 - 11.68)*	15.41 ± 2.23 (10.78 - 21.19)*	3.84 ± 0.77 (2.03 - 5.46)*	6.63 ± 1.25 (3.92 - 9.86)*	6.19 ± 0.83 (4.70 - 8.01)*
Work without crane *Rad bez dizalice*	3.56 ± 1.15 (1.07 - 7.17)*	7.05 ± 2.10 (3.6 - 12.07)*	2.17 ± 1.07 (0.44 - 6.54)*	3.73 ± 1.86 (0.82 - 12.58)*	3.49 ± 1.35 (1.55 - 10.16)*

Work components *Radne sastavnice*	Felling sites - Sječina				
	Otok	Gradiška	Gorica 1	Čazma	Gorica 2
Time consumption - *Utrošak vremena*, min					
Timber unloading (landing) *Istovar drva (stovarište)*	(4.71 - 10.60)*	(5.88 - 14.50)*	(1.89 - 5.65)*	(3.46 - 8.35)*	(3.72 - 7.77)*
Work with crane *Rad s dizalicom*	6.06 ± 1.13 (3.25 - 8.62)*	6.76 ± 1.58 (3.34 - 10.87)*	2.96 ± 0.60 (1.50 - 4.57)*	5.27 ± 0.89 (3.21 - 7.75)*	4.75 ± 0.69 (3.00 - 6.18)*
Work without crane *Rad bez dizalice*	1.41 ± 0.64 (0.18 - 3.17)*	2.07 ± 1.11 (0.60 - 7.39)*	0.50 ± 0.35 (0.11 - 2.48)*	0.68 ± 0.27 (0.21 - 1.42)*	0.89 ± 0.46 (0.14 - 2.61)*

* Minimums and maximums - *Najmanja i najveća izmjera*

It should be noted that at all researched felling sites forwarder drivers had problems with loader due to its insufficient lifting moment in loading and unloading larger assortments (2 m^3/pcs to 2.5 m^3/pcs). Processed assortments of higher volumes that could not be loaded by forwarder, were later on extracted to roadside landing by cable skidders.

TIMBER LOADING
UTOVAR DRVA

Boom out, boom in and pull over of assortments by hydraulic crane make the working components of crane work time (Fig. 21). Cycle time consumption of this group of working components is affected by: number of roundwood pieces in the forwarder loading area, roundwood dimensions and hence the load volume (Tufts 1997).

Due to different dimensions of processed roundwood within the felling units, and hence also within the forwarder load, the average piece volume is taken as the parameter presenting the mean assortment in the vehicle loading area. Considering the above mentioned dependence in Fig. 22, it can be concluded time consumption of crane work is exclusively affected by the number of roundwood pieces in the load.

Forwarder moving during loading, maneuvering, preparation of the crane for work and transport and forwarder turning off make the working components of time consumption of timber loading without crane. Time consumption of this group of working components is affected by density and size of processed technical roundwood per unit of cut block (Bulley 1999). This means that time consumption of this group of working components depends on distance and number of moving (i.e. the place of loading from which the forwarder driver loads the assortments within the reach of hydraulic crane) required to carry out optimum loading in respect of terrain factors.

Figure 21. Loading
Slika 21. Utovar

Due to high variability of time consumption of work without crane in loading within specific researched felling sites, arithmetic means were taken for the regression analysis (Fig. 23). The dependence was regressed by exponential equation with strong correlation ($R^2 = 0.65$).

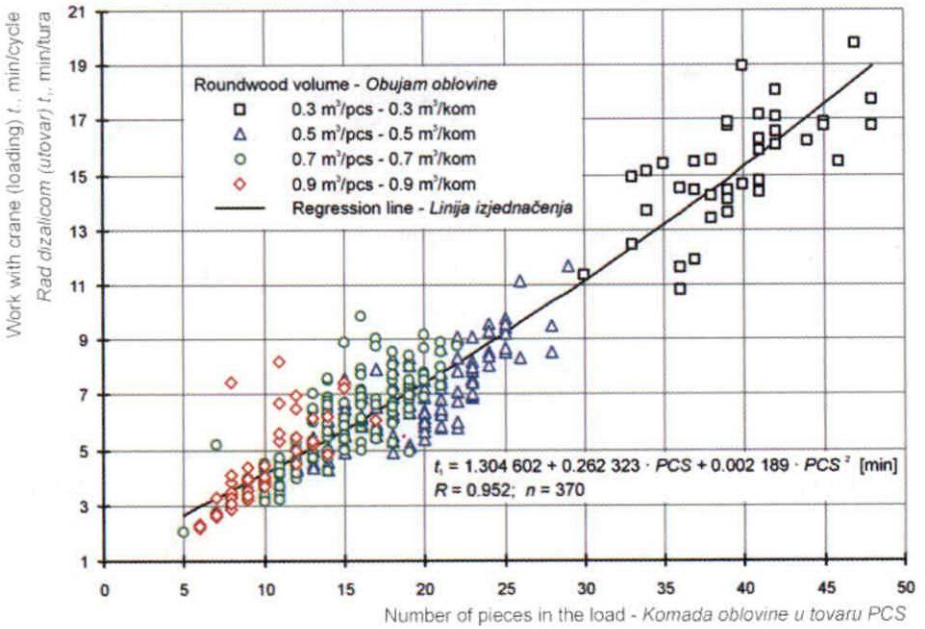

Figure 22. Work with crane vs. no. and roundwood volume
Slika 22. Ovisnost rada dizalicom o broju komada i obujmu oblovine

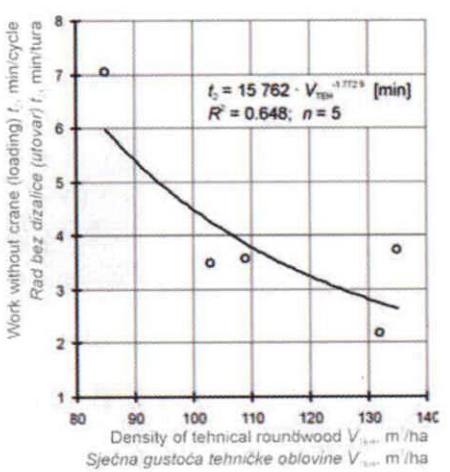

Figure 23. Work without crane
Slika 23. Rad bez dizalice

TIMBER UNLOADING
ISTOVAR DRVA

Time consumptions of work with crane in unloading is affected by the same factors as with loading. Figure 24 shows the impact of the roundwood volume on time consumptions of work with crane depending on number of pieces of loaded timber for classes of average piece volume (≤ 0.3 m^3, 0.5 m^3, 0.7 m^3 and ≥ 0.9 m^3). Two areas of data grouping can be seen from dependence:

- the group of average piece volume ≥ 0.5 m^3/pcs, where mostly one piece of roundwood was grasped in unloading with boom in hydraulic crane. Tipically for this group with the increase of number of pieces (ranging between 5 and 29 pieces) of roundwood in the loading area of the forwarder, time consumption of unloading with crane increased, too;
- the group of average piece volume ≤ 0.3 m^3/pcs, where mostly several (2 to 3) thinner pieces of roundwood (ranging betwen 30 and 48 pieces in the load) were grasped in unloading with boom in hydraulic crane, there is no express dependence of time consumptions on work with crane in unloading, as the result of unloading several pieces of roundwood in one grasp of boom in hydraulic crane. The arithmetic mean was, therefore, taken as the average time consumption for this group of data on time consumption of unloading with crane.

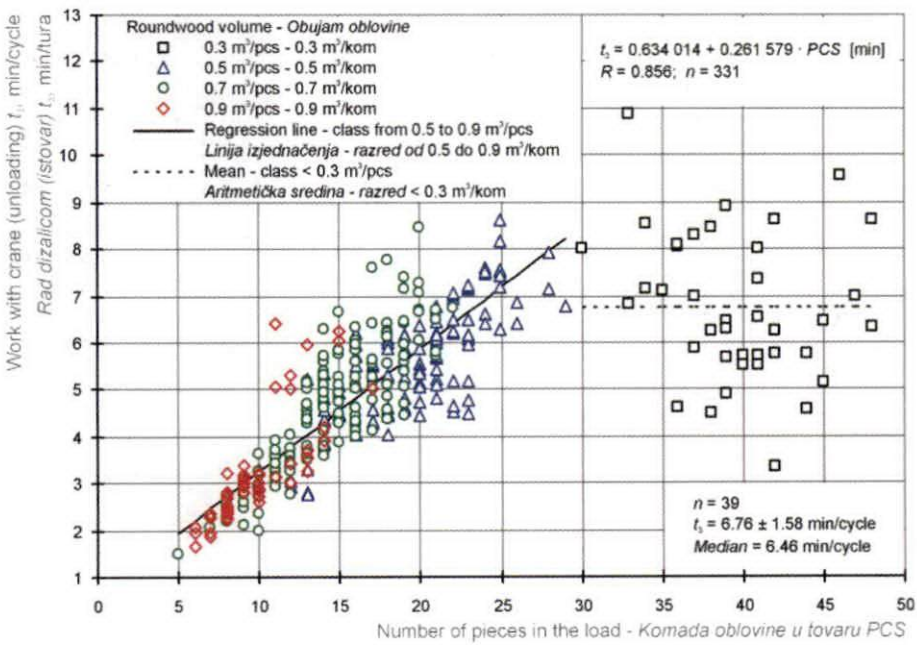

Figure 24. Work with crane vs. no. and roundwood volume
Slika 24. Ovisnost rada dizalicom o broju komada i obujmu oblovine

Figure 25. Unloading
Slika 25. Istovar

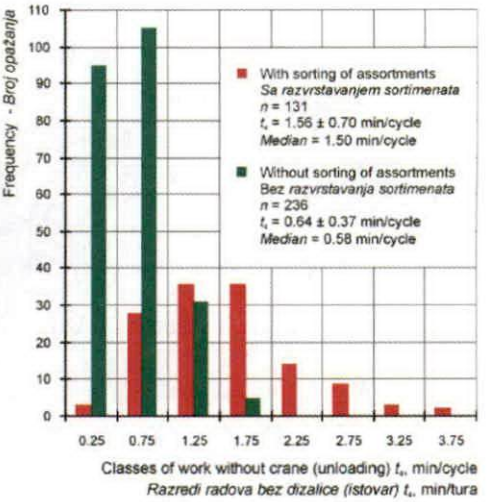

Figure 26. Work without crane (unloading)
Slika 26. Rad bez dizalice (istovar)

Time consumption of work without crane at timber unloading is affected by the need to sort timber at unloading into piles within the roadside landing, in case of different species of wood and quality classes in forwarder load, which brings to the increase of number and distance of forwarder maneuvering in unloading and hence also to the increase of time consumption of this group of working components (Gingras 1996, Gingras and Godin 1997). Krpan (1991) outlines that the arranged landings, where sorting of timber is carried out by forwarders, have impact on reducing the time of timber loading by trucks, which is especially important in case of simultaneous occurring of primary and secondary transport of timber.

Figure 26 shows the distribution of observation frequency of time consumption classes of work without crane in unloading, depending on whether sorting of assortments occurs or not. At researched felling sites, where there is no sorting of assortments at the roadside landing, time consumption of work without crane at unloading averages 0.64 ± 0.37 min/cycle, and when there is sorting of assortments, time consumption of this group of working components is 1.56 ± 0.70 min/cycle.

FORWARDER PRODUCTIVITY MODEL
OBLIKOVANJE PROIZVODNOSTI FORVARDERA

By bringing together the partial analysis of factors affecting the load volume and time consumptions of specific forwarder working components the model was developed for calculating forwarder productivity.

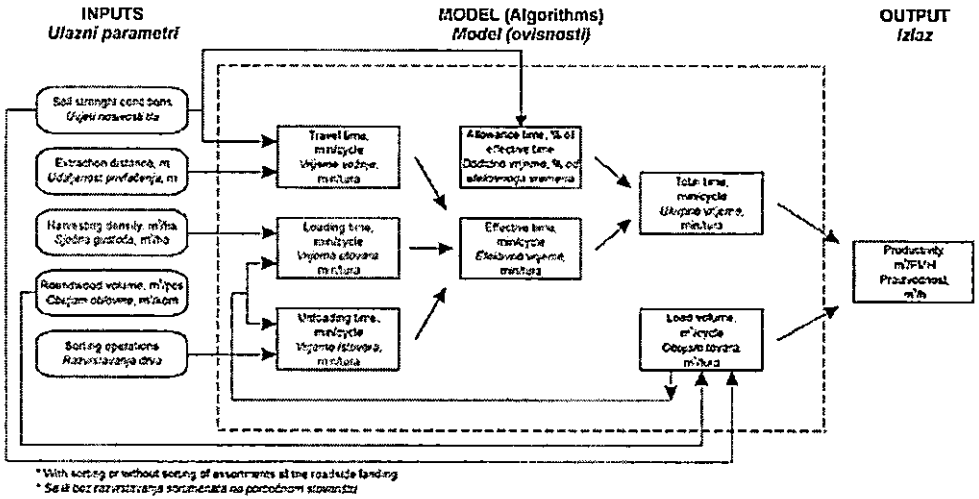

Figure 27. Forwarder productivity model

Slika 27. Model proizvodnosti forvardera

The model shown in Figure 27 calculates the forwarder productivity in accordance with the following formula:

$$V_h = \frac{60}{k_{ALL} \cdot \left\{ \left[s_1 \cdot \left(\frac{60}{v_1} + \frac{60}{v_2} \right) \right] + \left[s_2 \cdot \left(\frac{60}{v_3} + \frac{60}{v_4} \right) \right] + t_1 + t_2 + t_3 + t_4 \right\}} \cdot V_L \quad \left[\frac{m^3}{h} \right]$$

Symbol key -*Tumač simbola*

Symbol *Simbol*	Measuring item *Mjerna veličina*	Measuring unit *Mjerna jedinica*
V_h	Forwarder productivity *Proizvodnost forvardera*	m³/PMH m³/h
V_L	Load volume *Obujam tovara*	m³/cycle m³/tura
k_{ALL}	Factor of allowance time *Faktor dodatnoga vremena*	- -
s_1	Off-road forwarding distance *Udaljenost privlačenja drva po bespuću*	km km
v_1	Off-road travel speed of unloaded forwarder *Brzina kretanja neopterećenoga forvardera po bespuću*	km/h km/h
v_2	Off-road travel speed of loaded forwarder *Brzina kretanja opterećenoga forvardera po bespuću*	km/h km/h
Symbol *Simbol*	Measuring item *Mjerna veličina*	Measuring unit *Mjerna jedinica*

Symbol *Simbol*	Measuring item *Mjerna veličina*	Measuring unit *Mjerna jedinica*
s_2	Roadside landing forwarding distance *Udaljenost privlačenja drva po pomoćnom stovarištu*	km km
v_3	Travel speed of unloaded forwarder on roadside landing *Brzina kretanja neopterećenoga forvardera po stovarištu*	km/h *km/h*
v_4	Travel speed of loaded forwarder on roadside landing *Brzina kretanja opterećenoga forvardera po stovarištu*	km/h km/h
t_1	Time consumption of work with crane (felling site) *Utrošak vremena rada dizalicom (sječina)*	min/cycle min/tura
t_2	Time consumption of work without crane (felling site) *Utrošak vremena rada bez dizalice (sječina)*	min/cycle min/tura
t_3	Time consumption of work with crane (roadside landing) *Utrošak vremena rada dizalicom (stovarište)*	min/cycle min/tura
t_4	Time consumption of work without crane (roadside landing) *Utrošak vremena rada bez dizalice (stovarište)*	min/cycle min/tura

Due to partial determining of time consumption of individual groups of working components depending on the impact of the established influencing factor, the test was carried out of differences between realized productivity and modeled productivity. The results of testing confirmed that there were no significant differences between the results of realized productivity and modeled productivity.

CONCLUSIONS – DEPENDENCE OF FORWARDER PRODUCTIVITY VS. THE INFLUENCING FACTORS

ZAKLJUČCI – OVISNOST PROIZVODNOSTI FORVARDERA O UTJECAJNIM ČIMBENICIMA

The impact of the factors on the productivity of timber extraction by forwarder Timberjack 1210 was calculated on the basis of modeling the productivity in respect of specific influencing factors. The factors involved are as follows: soil strength conditions, distance of timber extraction, dimensions of processed timber, felling density of technical roundwood and sorting of assortments at roadside landing.

Due to frequently complex impact of many influencing factors on forwarder productivity, which cause a large number of possible work variants, only some of them are shown in this paper, while the others can be calculated by given time consumption models.

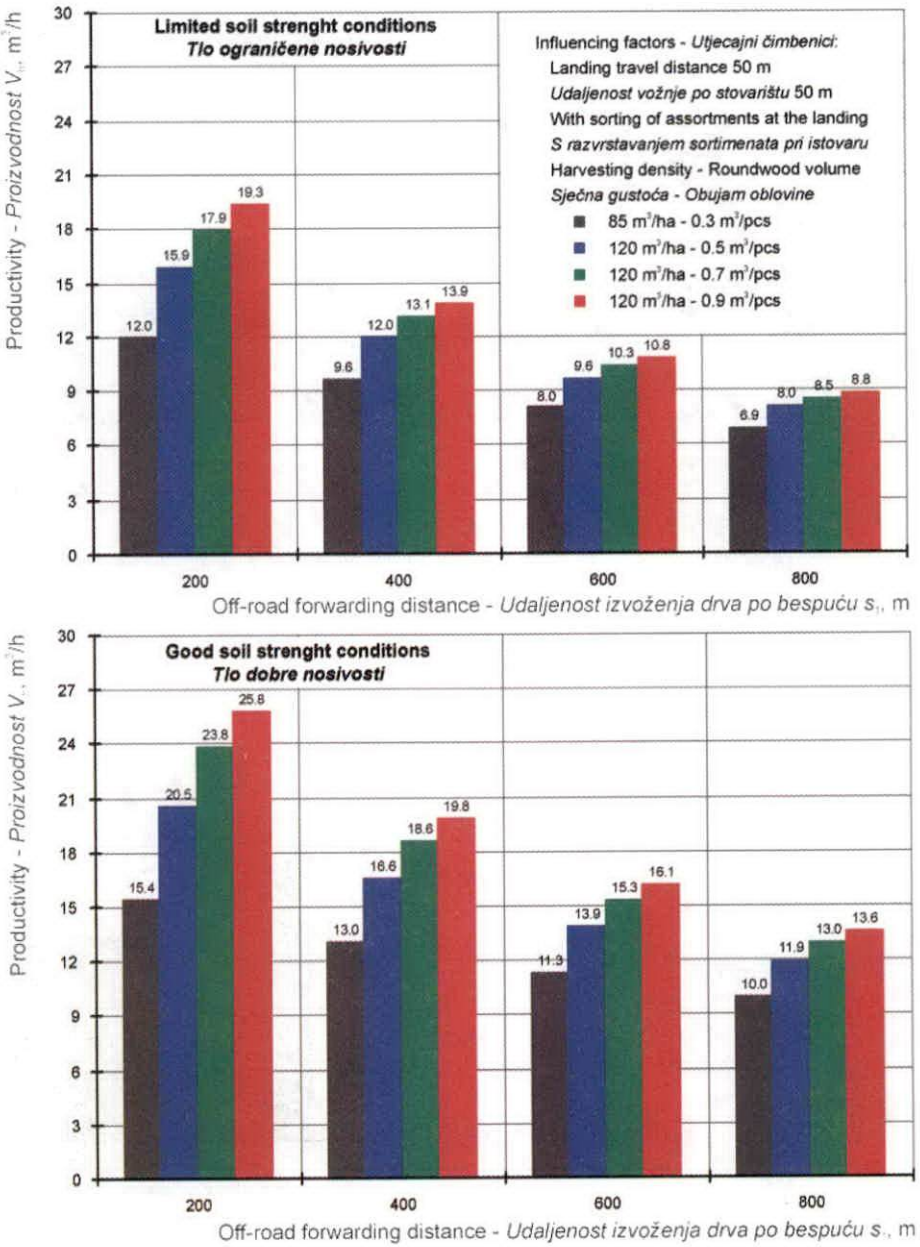

Figure 28. Productivity vs. soil conditions
Slika 28. Ovisnost proizvodnosti forvardera o uvjetima nosivosti tla

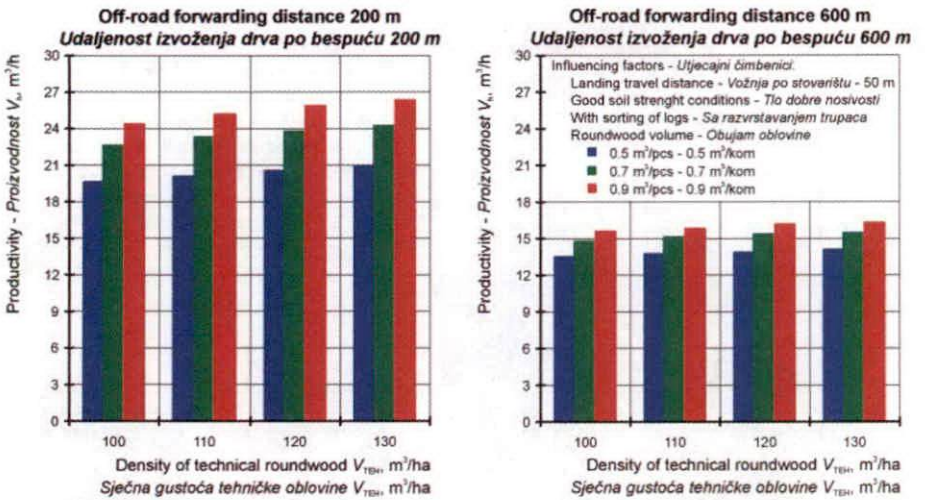

Figure 29. Productivity vs. density of tehnical roundwood

Slika 29. Ovisnost proizvodnosti forvardera o sječnoj gustoći tehničke oblovine

Figure 28 shows the impact of soil strength conditions and volume of roundwood on forwarder productivity within the extraction distance ranging between 200 m and 800 m. From the obtained results, it can generally be concluded that:

- reduction of productivity of forwarder timber extraction is seriously affected by limiting soil strength conditions and average roundwood volume in the load as well as by the increase of extraction distance,
- by increase of the roundwood volume in the load at a constant distance of timber extraction and under the same soil strength conditions, the forwarder productivity increases. However, with the increase of the distance of timber extraction, the differences between the productivity with classes of average piece volume in the load are reduced due to higher share of the vehicle travel time in total time of the modeled cycle,
- at shorter distances of timber extraction, forwarder productivity is highly affected by the roundwood volume in the load and with the increase of the forwarding distance its significance is lowered.

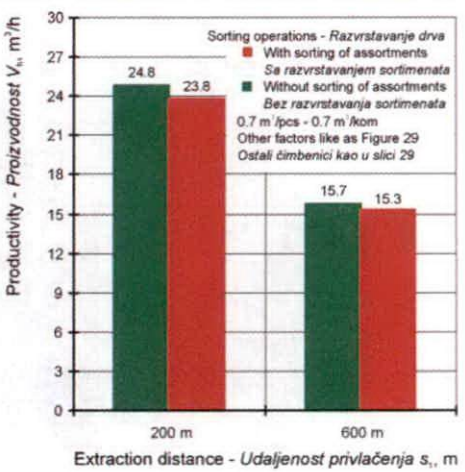

Figure 30. Productivity vs. landing operations

Slika 30. Utjecaj razvrstavanja sortimenata na proizvodnost forvardera

The increase of felling density of processed technical roundwood in the presented range, at a constant forwarding distance, affects only slightly the forwarder productivity. Its impact should be considered together with the roundwood dimensions of the processed assortment when it becomes significant (Fig. 29).

Sorting of assortments on roadside landing, affected slightly the decrease of forwarder productivity compared to the productivity achieved when the vehicle made no sorting of roundwood in unloading (Fig. 30). The increase of forwarding distance reduces the adverse effect caused by sorting of assortments on productivity of timber forwarding, due to higher share of travel in total cycle time.

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ČIMBENICI PROIZVODNOSTI FORVARDERA TIMBERJACK 1210 PRI IZVOŽENJU OBLOGA DRVA GLAVNOGA PRIHODA HRVATSKIH NIZINSKIH ŠUMA

SAŽETAK

Rad prikazuje utjecaj nekih čimbenika (udaljenost privlačenja drva, sječna gustoća, dimenzije izrađene oblovine, uvjeti stanja šumskoga tla te razvrstavanje sortimenata tijekom istovara) na proizvodnost izvoženja obloga drva glavnoga prihoda nizinskih šuma Hrvatske 12-tonskim forvarderom Timberjack 1210.

Istraživanja su provedena na pet sječina, u trajanju od 34 radna dana, za koje je vrijeme u 370 traktorskih turnusa privučeno 3 584 m^3 tvrdih listača (hrast i jasen). Zajedničko je obilježje rada forvardera na svim istraživanim sječinama izvoženje isključivo tehničke oblovine izrađene sortimentnom metodom motornim pilama te slobodno kretanje forvardera po površini sječnih jedinica pri skupljanju i utovaru drva. Razvrstavanje se sortimenata na pomoćnom stovarištu pri istovaru pojavljivalo u slučaju više vrsta ili klasa kakvoće obloga drva u tovaru forvardera. Sječine su se međusobno razlikovale prema: srednjim udaljenostima privlačenja drva (od 240 m do 610 m), stanju tla šumskoga bespuća tijekom istraživanja (od blatnoga do suhoga ili smrznutoga tla), sječnoj gustoći izrađene tehničke oblovine (od 85 m^3/ha do 132 m^3/ha) te prosječnim dimenzijama izrađenih sortimenata: srednjem promjeru oblovine (od 23 cm do 51 cm), duljini oblovine (od 3,6 m do 5,5 m) te njezinu obujmu (od 0,23 m^3/kom. do 0,72 m^3/kom.).

Proizvodnost traktora utvrđena je metodom tijeka rada i vremena, a utrošci su vremena pojedinih radnih sastavnica mjereni povratnom metodom kronometrije.

Na proizvodnost je forvardera u istraživanim sječinama utjecalo složeno djelovanje uvjeta stanja (nosivosti) tla, dimenzija sortimentnom metodom izrađene oblovine, sječne gustoće te razvrstavanja sortimenata na pomoćnom stovarištu pri istovaru. Zbog raznovrsnosti i raznorodnosti čimbenika koji su obuhvaćeni na objektima istraživanja, njihov je utjecaj na učinkovitost rada forvardera utvrđen posredno preko utrošaka snimljenih vremena te ostvarenih značajki tovara. Istraživanjem je utvrđeno:

—Obujam je tovara pod izrazitim utjecajem ključnoga terenskoga čimbenika nizinskih šuma – nosivosti tla. Također na obujam tovara djeluje i broj komada oblovine određenih dimenzija.
—Brzine kretanja neopterećenoga i opterećenoga forvardera ovise o vrsti podloge po kojoj se vozilo kreće (bespuće sa stanjima nosivosti šumskoga tla, šumska cesta s tucaničkim zastorom u području pomoćnoga stovarišta).
—Vremena rada dizalicom pri utovaru i istovaru ovise o broju komada oblovine određenih dimenzija u tovaru forvardera.
—Vremena radova bez dizalice pri utovaru pod utjecajem su sječne gustoće tehničke oblovine namijenjene primarnom transportu drva.
—Vremena radova bez dizalice pri istovaru ovise o potrebi za razvrstavanjem drva na

pomoćnom stovarištu u slučaju pojave više vrsta i klasa kakvoće obloga drva u tovaru forvardera.

—Dodatno je vrijeme ovisno o uvjetima nosivosti tla šumskoga bespuća.

Utjecaj čimbenika na učinkovitost izvoženja drva forvarderom Timberjack 1210 izračunat je na osnovi oblikovanja učinaka s obzirom na pojedini utjecajni čimbenik. Obuhvaćeni čimbenici su: uvjeti nosivosti tla, udaljenost izvoženja drva, dimenzije i veličina izrađene oblovine, sječna gustoća tehničke oblovine i razvrstavanje sortimenata na pomoćnom stovarištu.

Zbog čestoga složenoga djelovanja više utjecajnih čimbenika na učinak forvardera, koji uzrokuju velik broj mogućih inačica, prikazane su u radu samo neke, dok je ostale moguće izračunati pomoću danih modela utrošaka vremena.

Za dobivene rezultate može se općenito zaključiti da:

—Na smanjenje učinkovitosti izvoženja drva forvarderom izrazito utječu ograničavajući uvjeti nosivosti tla i prosječnoga obujma komada u tovaru te povećanje udaljenosti privlačenja.

—Povećanjem prosječnoga obujma komada u tovaru pri stalnoj udaljenosti izvoženja drva i uvjetima nosivosti tla učinkovitost forvardera raste, međutim, s povećanjem udaljenosti izvoženja drva razlike između učinkovitosti kod razreda prosječnoga obujma komada u tovaru smanjuju se zbog povećanja udjela vremena kretanja vozila u ukupnom vremenu oblikovanoga turnusa.

—Na kraćim udaljenostima privlačenja drva na učinkovitost forvardera izrazito utječe prosječan obujam komada u tovaru, dok povećanjem udaljenosti privlačenja njegovo značenje opada.

—Povećanje sječne gustoće izrađene oblovine pri stalnoj udaljenosti privlačenja neznatno utječe na učinkovitost forvardera, međutim njezin utjecaj treba promatrati zajedno s prosječnim obujmom izrađene oblovine kad ona dobiva na značenju.

—Razvrstavanje sortimenata na pomoćnom stovarištu neznatno je utjecalo na smanjenjenje učinkovitosti forvardera u odnosu na učinkovitost kad vozilo ne razvrstava oblovinu prilikom istovara. Povećanjem udaljenosti privlačenja smanjuje se negativno djelovanje razvrstavanja sortimenata na proizvodnost privlačenja drva zbog porasta udjela kretanja vozila u ukupnom vremenu turnusa.

Ključne riječi: proizvodnost forvardera, utjecajni čimbenici, oplodne sječe, nizinske šume u Hrvatskoj