Transport of Technical Roundwood by Forwarder and Tractor Assembly from Poplar Plantations

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Abstract – *Nacrtak*

This article presents the results of a research dealing with operating efficiency of articulated and tractor assemblies in the plots of poplar plantations in which different means of work were used for felling and cross-cutting. The aim was to study the effects of the arrangement of wood assortments on the driving speed of the vehicle, the time needed to load and manipulate the vehicle and the overall working efficiency of forwarders. The research was carried out in Vojvodina, in the area of PE »Vojvodina šume«. Altogether 170 transport cycles were recorded and 2166.73 m^3 transported. The research results show that the forwarder moved faster on the felling site where the felling and cross-cutting operations were carried out by a harvester. The speed was 10% higher and it took 5% less time to load the forwarder. The differences were considerably greater concerning the manipulation time (maneuvering and positioning the vehicle during the loading). The driving speed decreased with an increase in the load volume. Fuel consumption was lower in the felling site where a harvester was used for felling. Under the same working conditions, the tractor assembly achieved better productivity because it drove at considerably higher speeds. The differences in the average load volume were not so great, which significantly affected the productivity of the tractor assembly. The initial hypothesis that a forwarder achieves better working efficiency in the felling site, where a harvester has been used in the operations of felling and cross-cutting, was confirmed.

Keywords: John Deere 1210E forwarder, tractor assembly, first phase of transport, poplar technical roundwood, efficiency, costs

1. Introduction – *Uvod*

Technical roundwood of soft and hard broadleaves is transported in lowland areas by both tractor and articulated vehicles. Tractors are mainly intended for the transport of technical roundwood from the thinning of hard broadleaves and for the transport of thinner assortments (long pulpwood, extended firewood, etc.) from soft broadleaved plantations. The use of the tractor assembly does not necessarily exclude the use of articulated vehicles, at least not in the territory of Serbia. In Serbia, tractors are more often used on level to moderately steep terrains. The choice of vehicles is determined by the state of the terrain (size and frequency of obstacles in a felling site, bearing capacity of the soil), structure of the material and transport distance. The use of forwarders in the forestry of Serbia is related to difficult terrains (swamp forests), and tractor assemblies are generally used in more favorable conditions (flood protected terrains). Under such conditions, the operating costs are lower if a tractor assembly is used compared to the costs of articulated vehicles (Đoković and Jezdić 1980). Unlike forwarders, tractor assemblies are used in more favorable conditions, at longer distances, often even in the second phase of timber transport (Danilović et al. 2012).

The operating efficiency of forwarders is affected by a number of different factors: tree species, silvicultural treatments, terrain conditions, average haulage distance, timber density on the strip road and load volume, operator skills (Nikolić and Jezdić 1983, Sever 1988, Tufts and Brinker 1993, Kellogg and Bettinger 1994, Kuitto et al. 1994, Tiernan et al. 2004, Poršinsky 2005, Väätäinenet al. 2005).

A reduction in the load volume can greatly affect the efficiency of the forwarder, particularly if the hauling distance is increased. Reducing the load to 2/3 of the load space compared to the nominally loaded forwarder (12 t load) reduces its efficiency by 16% (for a 100 m distance) or by 28% (for a 800 m distance) (Poršinsky et al. 2011). Zimbalatti and Proto (2010) point out that, provided the assortment method is applied, the efficiency of John Deere 1110D forwarder model correlates strongly with the size of the load and mean transport distance.

There are comparatively large forest areas in Vojvodina that are located in the foreland of its major rivers. They are characterized by frequent flooding, i.e. low bearing capacity of the substrate. From a technical point of view, forwarders are better suited for such conditions (Danilović et al. 2012).

The state of the substrate and the load weight affect the fuel consumption. Fuel consumption is important both from the economical and ecological point of view, since it affects the transport costs on the one hand and emissions of the pollutants into the atmosphere on the other. Berg and Lindholm (2005) reported a significantly higher emission of pollutants in forestry operations in the Scandinavian countries than those shown in previous results. The average consumption of diesel fuel in felling, cross-cutting, and in the first phase of transport amounts to 1.48–1.78 L/m^3 (Michelsen et al. 2008). Johnson et al. (2005) reported similar amounts of diesel fuel used for felling trees in the northwest of the United States (1.70 L/m^3). According to Jezdić et al. (1995) diesel consumption for a five-year period in FE »Sremska Mitrovica« was an average of 1.17 L/m^3. Surface conditions (the height and number of obstacles) affect the working efficiency of forwarders.

2. Research problems and aims *Problematika i cilj istraživanja*

In poplar plantations in Serbia, clear cutting is applied at the end of the production cycle, which is about 20 years long. From a technological point of view, clear cutting has many advantages, considering the greater technology freedom it permits. Under these conditions, a large amount of assortments, usually over 300 m^3/ha, is concentrated on a small area. Felling and cross-cutting are generally performed using chainsaws and applying the 1M+1R organizational form of work (M – chainsaw logger, R – assistant worker). After trees have been felled and wood assortments crosscut with a chainsaw, evenly spaced assortments remain in the felling site. However, apart from chainsaws, John Deere 1470D ECO III harvester has been used in FE »Sremska Mitrovica« for felling and cross-cutting since 2008. When the harvester is used, the order of assortments on the worksite is improved, which allows a more efficient use of the equipment in the first phase of transport. In other words, the felled logs are lined in smaller piles, which makes the manipulation of the forwarder easier and shortens the passage time during loading. The loading is faster and the forwarder attains a higher speed between the loading and unloading site (Danilović et al. 2011). This was one of the reasons to study the operating efficiency of forwarders in these conditions.

Accordingly, the aim of this research study was to investigate the operating efficiency of John Deere 1210E Forwarder, which is used after a clear-cutting has been performed with a chainsaw and by John Deere 1470D Eco III Harvester. Another aim was to compare the efficiency of John Deere 1210E Forwarder with the efficiency of the tractor assembly in the same working conditions.

The starting hypothesis is that the arrangement of assortments in the felling site, where the harvester has been used for felling and cross-cutting, has positive effects on the forwarder efficiency, meaning that the speed of the forwarder moving on the felling site will be higher. Apart from that, we assume that the loading time will be shorter because, after felling and cross-cutting, the harvester groups the logs. Furthermore, we assume that the operating costs of the tractor assembly will be lower than the operating costs of forwarders under the same working conditions.

3. Materials and methods – *Materijal i metode istraživanja*

The operations of the transport vehicles were recorded in three sample plots (SP). Felling and cross-cutting operations in SP1A and SP1B were performed with a chain saw, while in SP2 it was done using a harvester in the case of technical roundwood, and Stihl 260 chainsaw in the case of short pulpwood. The basic characteristics of the plantation and terrain are presented in Table 1.

The weather did not show any significant changes during the recording time. It was sunny and the soil was dry. The forwarder operators were well trained and they have been achieving satisfactory results in this kind of work for many years.

When the harvester was used for felling trees, the assortments were grouped at the acute angle to the direction of harvester movement, while in the case of chainsaw felling it was impossible to group the assort-

Table 1 Basic characteristics of the plantation (felling site)
Tablica 1. *Osnovna obilježja plantaža (radilišta)*

Plantation age at the time of harvest (SP1A and SP1B), years – *Dob plantaže u vrijeme sječe (PP1A i PP1B), godine*	25
Plantation age at the time of harvest (SP2), years – *Dob plantaže u vrijeme sječe (PP2), godine*	26
Planting spacing (SP1A and SP1B), m – *Razmak sadnje (PP1A i PP1B),* m	6×6
Planting spacing (SP2), m – *Razmak sadnje (PP2),* m	
Number of trees per ha at the time of establishment – *Broj stabala po ha u vrijeme osnivanja*	278
Number of trees per ha on SP1A and SP1B at the end of rotation *Broj stabala po ha na PP1A i PP1B na kraju ophodnje*	268
Number of trees per ha in SP2 at the end of rotation – *Broj stabala po ha na PP2 na kraju ophodnje*	231
Mean diameter at breast height (SP1A and SP1B), cm – *Srednji promjer na prsnoj visini stabla (PP1A i PP1B),* cm	41
Mean diameter at breast height (SP2), cm – *Srednji promjer na prsnoj visini stabla (PP2),* cm	38
Net harvested volume (SP1A and SP1B), m^3/ha – *Neto sječna gustoća (PP1A i PP1B),* m^3/ha	396
Net harvested volume (SP2), m^3/ha – *Neto sječna gustoća (PP2),* m^3/ha	287.7
Slope, % – *Nagib,* %	$\approx 0°$
Harvesting method – *Metoda sječe*	Clear–cut – *Čista sječa*
Soil type (SP1A and SP1B) – *Tip tla (PP1A i PP1B)*	Fossil humogley – *Ritska crnica*
Soil type (SP2) – *Tip tla (PP2)*	Semigley – *Semiglej*

Note: Sample plot (SP) – *Bilješka: Pokusna ploha (PP)*

ments, which resulted in the crisscrossing of the felled trees (Fig. 1 and 3). During the loading of wood assortments in SP2, the forwarder moved between the rows, or along the strips that were bordered by piled assortments on both left and right side. Apart from that, there were some branches between the piles, which is not the case when felling and cross-cutting are carried out using a chainsaw. Wood assortments were transported to the felling site and along the skid trail to the hard truck road where there was a temporary landing. The average values for the measured elements of the studied transport cycles are shown in Table 2.

The work time study was applied for the purposes of this research. A digital watch was used to measure the duration of the operations, applying the flow method, with an accuracy of up to one second. The following forwarder operations were recorded: manipulation at temporary landing, drive to uplift the load, manipulation in the felling site, loading of wood assortments, crossing during loading, and return from the felling site to the unloading site.

All downtime periods during the forwarder operation were recorded, especially those related to free movement of the forwarder between the piles of wood assortments sorted by the harvester in the course of felling and cross-cutting operations, since the starting hypothesis is that in this case it takes less time to load the logs and to cross from one point to another than

Table 2 Values of the measured elements in sample plots
Tablica 2. *Vrijednosti izmjerenih elemenata na pokusnim plohama*

Measured parameter – *Mjereni parametar*	Sample plot 1A *Pokusna ploha 1A*	Sample plot 2 *Pokusna ploha 2*	Sample plot 1B *Pokusna ploha 2B*
Number of transport cycles – *Broj ciklusa izvoženja*	54	40	76
Average log volume, m^3/pcs – *Prosječni volumen sortimenta,* m^3/kom.	0.35	0.34	0.33
Total volume of transported assortments, m^3 – *Ukupni obujam izvezenih sortimenata,* m^3	718.85	474.00	973.88
Maximum volume of a load, m^3 – *Najveći obujam ciklusa izvoženja,* m^3	15.18	12.33	15.28
Minimum volume of a load, m^3 – *Najmanji obujam ciklusa izvoženja,* m^3	12.81	11.12	9.89
Average volume of a load, m^3 – *Prosječni obujam ciklusa izvoženja,* m^3	13.07	11.85	12.81

when the forwarder moves on the felling site where the cutting has been performed with a chainsaw. The transport distances of the full and empty drive were measured with an accuracy of up to 1 m. GPS device Mobile Mapper 10 was used for the measurement. This paper used conventional statistical and mathematical methods. Statgraphic Plus was used for statistical data processing.

4. Study area – *Područje istraživanja*

The research was carried out in the regular cuttings of poplar plantations Populus × euramericana 'I-214' in Vojvodina. The performance of John Deere 1210E forwarder in the first phase of transporting technical round wood was recorded in a felling site of the FE »Sremska Mitrovica«, where felling and cross-cutting operation was performed by John Deere 1470D Eco III harvester (Fig. 2), and in a felling site of the FE »Banat«, »Pančevo«, where the harvesting was carried out with a chainsaw (Fig. 1). The same felling site was used to record the work of the tractor assembly that consisted of Same Laser 130 tractor, Imako 12 t trailer and Loglift F61, F71 boom (Fig. 3).The transport of wood assortments was carried out in May and June 2012 and 2013.

5. Research results – *Rezultati istraživanja*

The total volume of timber transported during the recording period was 2 166.73 m^3. The values calculated for certain elements of the transport cycle are shown in Table 3.

The average speed of the forwarder when driving to take the load (empty vehicle) in all transport cycles in

Fig. 1 Full forwarder in sample plot 1A
Slika 1. *Natovareni forvarder na pokusnoj plohi 1A*

Fig. 2 Loading of assortments in sample plot 2
Slika 2. *Utovar sortimenata na pokusnoj plohi 2*

Fig. 3 Loading of assortments in sample plot 1B
Slika 3. *Utovar sortimenata na pokusnoj plohi 1B*

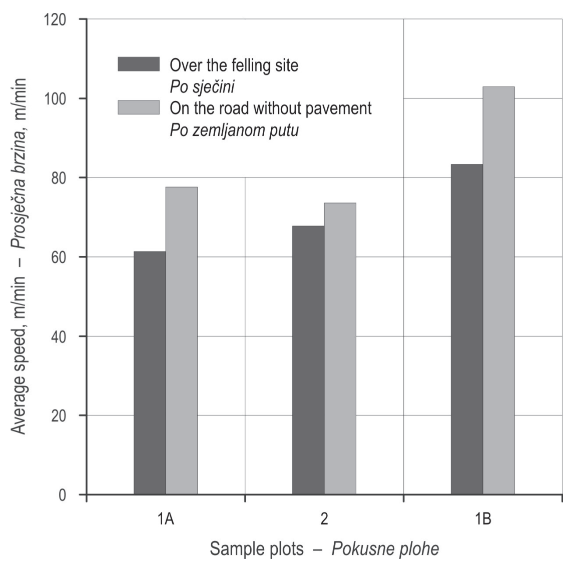

Fig. 4 Average speed on sample plots
Slika 4. *Prosječna brzina na pokusnim plohama*

Table 3 Elements of a transport cycle

Tablica 3. *Vrijednosti elemenata transportnoga ciklusa*

Measured parameter – *Mjereni parametar*	Sample plot 1A *Pokusna ploha 1A*	Sample plot 2 *Pokusna ploha 2*	Sample plot 1B *Pokusna ploha 2B*
Mean transport distance on the felling site, m – *Srednja udaljenost izvoženja na radilištu,* m	753.0	278.5	1839.6
Mean transport distance on the road without pavement, m *Srednja udaljenost izvoženja na zemljanom putu,* m	398.7	320	263.6
Mean converted transport distance, m – *Srednja pretvorbena udaljenost izvoženja,* m	1003.4	396.4	2052.7
Coefficient of conversion – *Koeficijent pretvorbe*	0.737	0.809	0.628
Average speed on the felling site, m/min – *Prosječna brzina na radilištu,* m/min	61.3	67.8	83.3
Average speed on the road without pavement, m/min *Prosječna brzina na zemljanom putu,* m/min	77.6	73.6	102.9
Loading time, min/m^3 – *Vrijeme utovara,* min/m^3	0.99	0.95	1.24
Unloading time, min/m^3 – *Vrijeme istovara,* min/m^3	0.34	0.31	0.59
Average distance when crossing the felling site during loading, m *Prosječna udaljenost premještanja na radilištu kod utovara,* m	43.0	31.6	22.9
Crossing and manipulation time, min/cycle – *Vrijeme prelaženja i manevriranja,* min/ciklus	3.50	1.90	2.7
Manipulation time on the roadside landing, min/cycle *Vrijeme manevriranja na pomoćnom stovarištu,* min/ciklusu	0.81	0.74	0.91

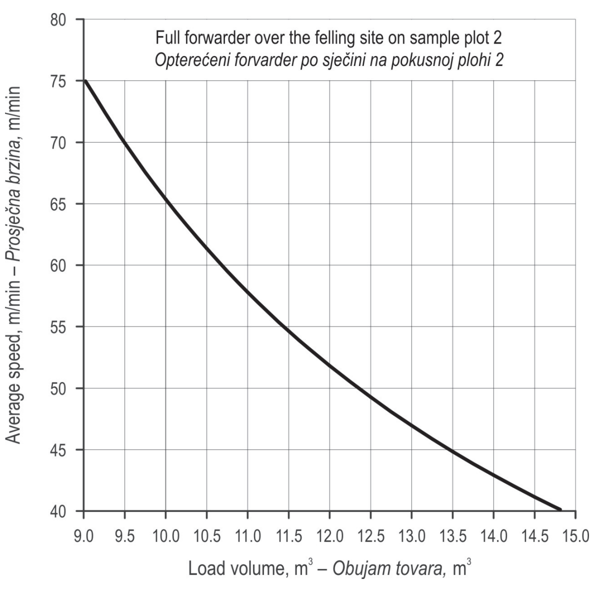

Fig. 5 Dependence of the average forwarder speed (full vehicle) in the felling site on load volume

Slika 5. *Ovisnost prosječne brzine opterećenoga forvardera o obujmu tovara na radilištu*

SP1A was 71.6 m/min, while it amounted to 62.1 m/min on the way back (full vehicle). When the forwarder moved along the dirt roads of the poplar plantation, its average speed was 81.5 m/min when it was empty and 74.0 m/min when it was full. In SP2, the forwarder reached the average speed of 81.8 m/min when driving to take the load and 58.2 m/min on the way back. The average speed of the forwarder on the dirt road was 78.5 m/min when it was empty and 69.8 m/min when it was full.

The average speed of the vehicle in the felling site of SP1A was significantly different from the average speed of the vehicle in SP2 ($F = 7.2$, $p = 0.009$). The correlation between the speed of a full vehicle and the load volume was studied in SP2, where the differences between the minimum and maximum load volume were the greatest.

The average movement time of a loaded transport vehicle is shorter than the time achieved by an empty transport vehicle, regardless of the road category. The difference in the speed was the greatest in the felling site in which a harvester was used for felling and cross-cutting and it amounted to 28.6%.The correlation between the average time spent on the movement of the full forwarder on the felling site in SP2 (Fig. 5) and the load volume is presented by the following formula:

$$V_s = \frac{1}{(-0.0047 + 0.002 \cdot q)}, \; (R = 0.533,\; Sr = 0.0033)$$

The time needed for loading and unloading is dependent on the average log volume and load volume (Tafts and Brinker 1993, Gullberg 1997, Väätäinen et al.

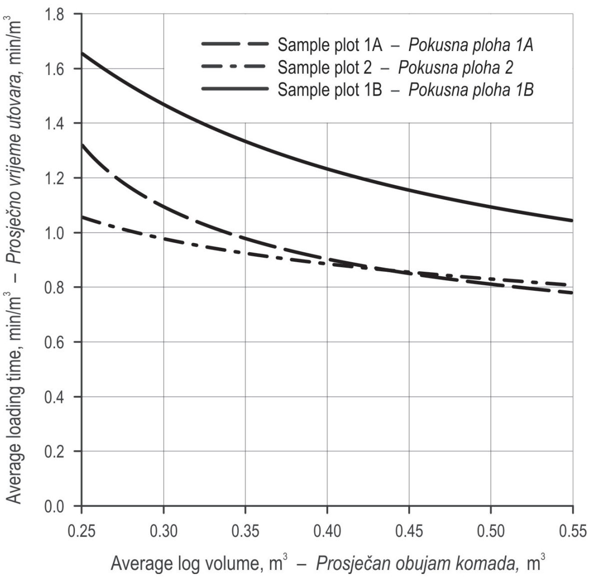

Fig. 6 Dependence between the loading time and the average log volume

Slika 6. *Ovisnost vremena utovara o prosječnom obujmu komada*

2005). Besides, the loading time varies with the arrangement of the assortments in the felling site, which motivated us to carry out this research. The loading time, expressed in min/ m³, decreases with an increase in the log volume (Fig. 6).

The loading time decreases with an increase in the log volume, and this correlation is moderate to high (R ranges from 0.493 to 0.543). The function models of the studied correlation are presented in Table 4.

Table 4 Regression models for the correlation between the loading time and average log volume

Tablica 4. *Regresijski modeli ovisnosti vremena utovara o prosječnom obujmu komada*

Sample plots *Pokusne ploha*	Function – *Ovisnost*	R^2	*Sr*
1A	$t_u = \frac{1}{\left(1.717 - \frac{0.239}{m}\right)}$	26.0	0.122
1B	$t_u = 0.597 + \frac{0.115}{m}$	24.3	0.074
2	$t_u = 0.542 + \frac{0.277}{m}$	29.8	0.089

Note: loading time – t_u, average log volume, m³
Bilješka: vrijeme utovara – t_u, prosječni obujam sortimenta, m³

This time is also affected by the number of logs that are simultaneously loaded with one grip of the hydraulic boom. Sometimes the hydraulic grapple grips several logs at the same time, which reduces the good effects of the greater volume of logs. This is less frequent in the felling site where chain saws have been used for felling and cross-cutting, because the logs are crisscrossed there, so it is less possible to lift several logs in one grip. Even if it were possible, it would take more time to make a grip than when only one log is loaded. This is not the case with unloading the wood assortments because less time is wasted on making a grip. The results of the analysis of variance show that there is a statistically significant difference ($F = 101.9$, $p = 0.000$) in the average time needed to load technical roundwood in the study area. There are differences in the loading time between the tractor assembly and forwarder, but there is no difference in the loading time of forwarders, regardless of the cutting method ($F = 3.58$, $p = 0.061$). The unloading time was not studied, given the differences in the time of loading. However, in this case, the hypothesis that there are significant differences in the loading time depending on the harvesting method was not proven, although the log volume was approximately the same.

The average manipulation time (moving and positioning of the vehicle) when loading the wood assortments was the longest in SP1A and the shortest in SP2. There was no statistically significant difference in the manipulation time between SP1A and SP1B ($F = 1.310$, $p = 0.255$). The average manipulation time in these

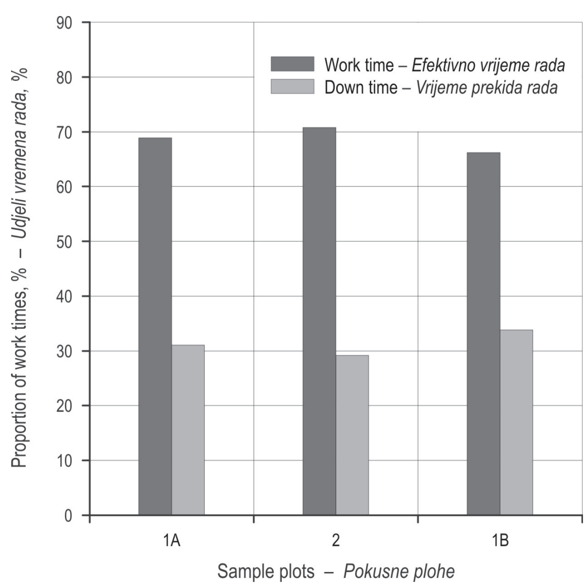

Fig. 7 Proportion of work time to downtime

Slika 7. *Udio efektivnoga vremena rada i vremena prekida rada*

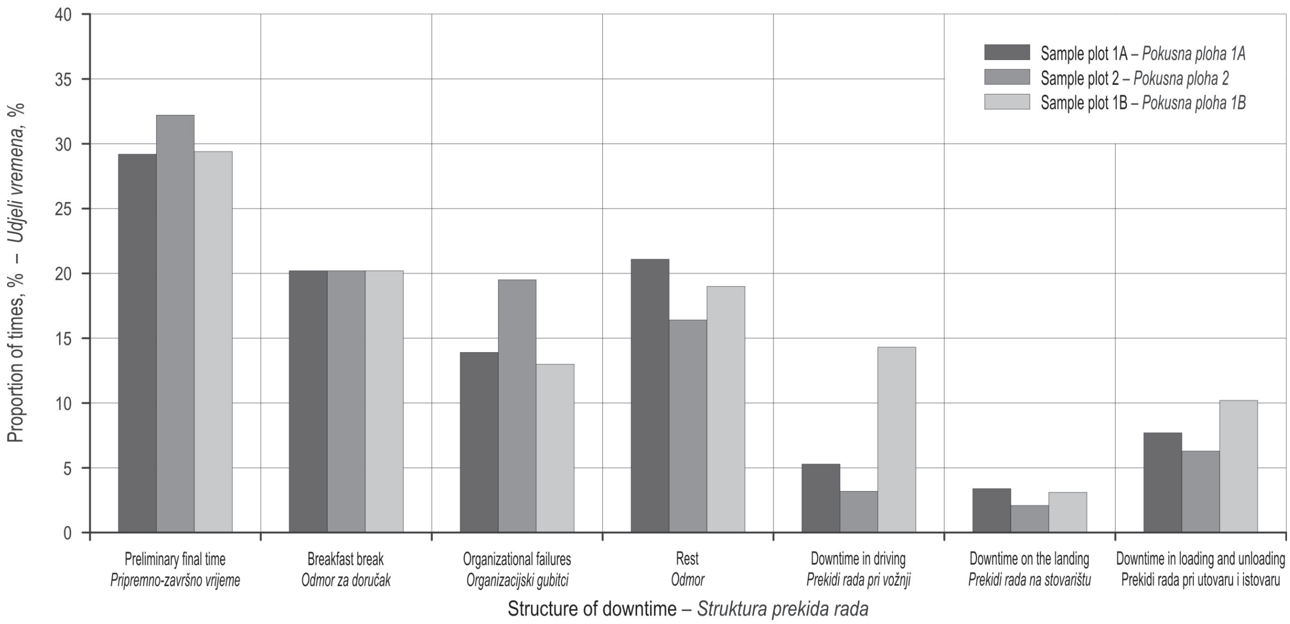

Fig. 8 Structure of downtime
Slika 8. *Struktura vremena prekida rada*

sample plots amounted to 0.23 min/m^3. On the other hand, there was a statistically significant difference in the forwarder manipulation time between SP1A and SP1B ($F = 68.85$, $p = 0.000$). The average manipulation time in SP2 was 0.16 min/m^3.The proportion of work time to downtime is shown in Fig. 4. The work time of the studied vehicles ranged from 66.2% to 70.8%. The proportion of downtime was the greatest in transporting technical roundwood by tractor assembly (Fig. 7).

The greatest share of downtime refers to preliminary final time. Breaks and rests account for a slightly smaller share. The share of downtime due to organizational failures ranges from 13 to 19.5% of the total downtime, depending on the vehicle (Fig. 8).

The share of downtime in full and empty drive is different and it depends on the type of vehicle used. It is the smallest in SP2 and amounts to 3.2% of the total downtime, while it is the greatest in the movement of the tractor assembly and amounts to 14.3%. The share of downtime is greater in SP1A than in SP2, which is probably due to the arrangement of wood assortments in the stand. The length of downtime in loading and unloading is the shortest in SP2 which is due to the arrangement of wood assortments in the felling site. The share of downtime was affected by the operator skills, the state of the vehicle, organization of the working operations, etc. Good organization of work actually means that it is a great advantage if there is a place near the felling site where the vehicle can be parked at the end of a working day. Basically, this has been a practice in the FE »Sremska Mitrovica« for a long time and recently in the FE »Pančevo«, as well. This practice is time efficient, meaning that the vehicles achieve better productivity.

Fuel consumption was determined by the method of refilling the tank. The fuel was transported to the place where the vehicle was parked and then poured into the tank. Upon completion of the work, the tank was refilled. The vehicle had to be parked on a level surface during the process. The fuel was refilled to the top of the fuel tank, and the tank was checked at the beginning of the working process in case it had to be filled up with fuel. The fuel consumption refers to working time of the tractor engine (running tractor). The results of the measurements are shown in Table 5.

Table 5 Fuel consumption
Tablica 5. *Potrošnja goriva*

	Sample plots – *Pokusne plohe*		
	1A	2	1B
Fuel consumption *Potrošnja goriva*	L/h		
	11.84	8.17	11.05
	L/m^3		
	0.92	0.77	0.91

The coefficients for converting the mean transport distance on a dirt road into the mean transport dis-

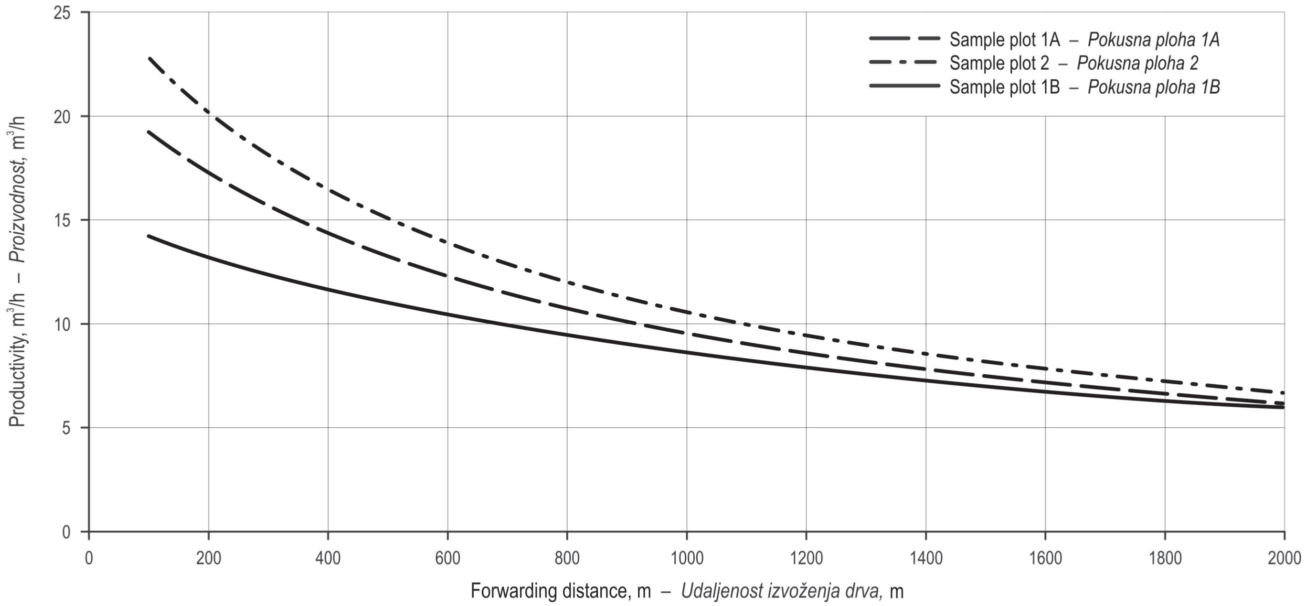

Fig. 9 Dependence of the productivity on forwarding distance
Slika 9. *Ovisnost proizvodnosti o udaljenosti izvoženja drva*

tance on the felling site are given in Table 3. The average outputs that the tractor achieves when transporting technical roundwood, with the average log volume amounting to 0.3 m^3, are presented in Fig. 9.

Direct daily operating costs of John Deere 1210E forwarder, calculated based on standard calculations, amount to 463.2 €/day, while the costs of the tractor assembly amount to 207.6 €/day.The purchase price of a forwarder is EUR 288,000, and of the tractor assembly EUR 76,335. The annual interest rate is 6.5%. Amortization period for both types of vehicles is 5 years, and the price of fuel is 1.36 €/L. The unit costs

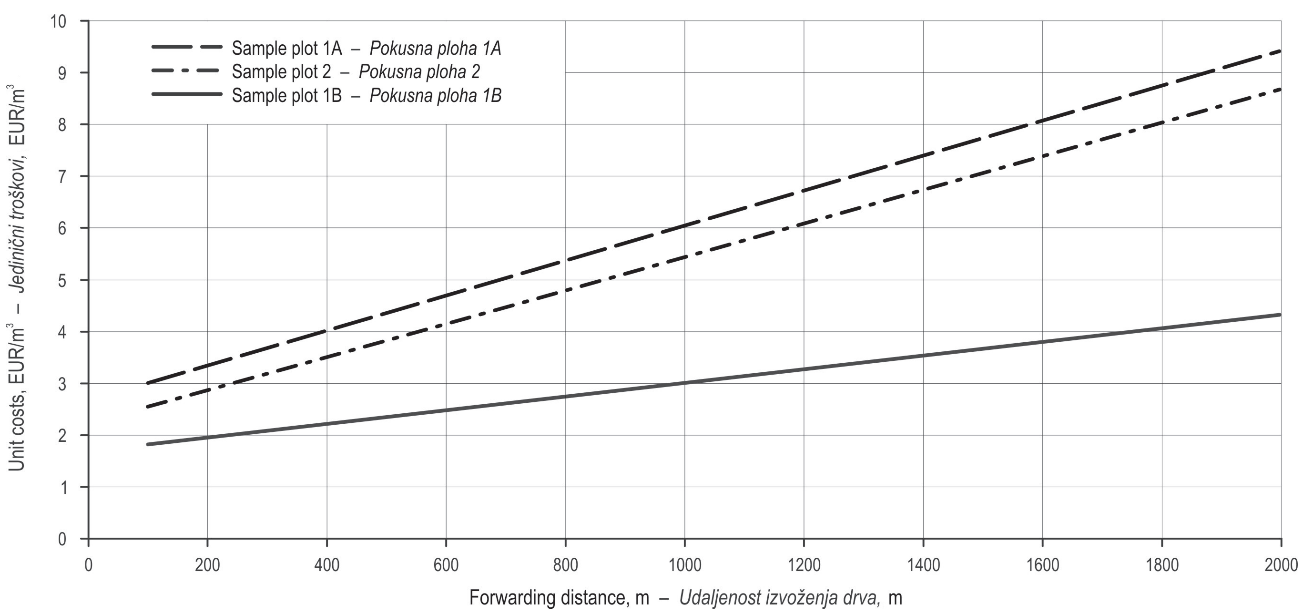

Fig. 10 Dependence of unit costs on forwarding distance and log volume
Slika 10. *Ovisnost jediničnoga troška o udaljenosti izvoženja drva i obujmu komada*

were calculated based on daily direct labor costs and the achieved outputs. Fig. 10 shows the unit costs and their dependence on the transport distance and log volume.

6. Discussion – *Rasprava*

The efficiency of the vehicles used in the operations of the first phase of transport in lowland areas has been the subject of a number of studies, which have quantified the effects of different factors. This research is based on the fact that multifunctional machinery is commonly used in the forestry of Serbia, especially in the operations of felling and cross-cutting of wood assortments in the plantations of soft broadleaves. John Deere 1470D ECO III harvester achieves significant outputs in the operations of felling and cross-cutting in regular cuttings of poplar plantations, but if we compare the unit costs of felling and cross-cutting operations carried out by a harvester with the costs of the same operations done with a chainsaw, we can see that, under the same working conditions, the unit costs are considerably lower when a chainsaw is used (Danilović et al. 2011).This is due to the high fixed costs of felling and cross-cutting by a harvester in comparison to the fixed costs of the same operations performed using a chainsaw. The differences in the costs are bigger in the case of long pulpwood. All the benefits should be considered by studying the working efficiency in the phase of felling and cross-cutting and in the phase of transporting the wood assortments. The use of different equipment for felling and cross-cutting has different impacts on the working efficiency of the equipment used in the operations of transporting wood assortments.

The results of these investigations show that there are differences in the basic working norms (average speed of the vehicle moving on the felling site, average loading time and average manipulation time in the felling site) between the investigated means of work. These differences confirm the initial hypothesis that it is more advantageous to use a forwarder in the felling site, where felling and cross-cutting have been performed by a harvester. The difference in the average driving speed of forwarders in these two sample plots is about 10%, which can be attributed to some extent to the difference in the harvesting method applied (Fig. 4). Since this research study has not been carried out in strictly controlled conditions, there are some other factors that could not be determined, but could possibly affect the results. The time needed to drive both a full and an empty vehicle vary with the distance and driving speed, which are generally affected by geophysical factors (Manner et al. 2013). The average speed achieved by the forwarder in the felling site, where the chainsaw was used for felling, is not significantly different from the speed values obtained in previous research studies carried out in similar conditions (Jezdić et al. 1999, Danilović 2010, Danilović et al. 2012b). In this case, the branch wood that remained on the strips after felling and cross-cutting by a harvester could not significantly affect the movement of a forwarder, because the soil was dry.

The loading time is slightly shorter when transporting wood from the felling site where the prior felling has been performed by a harvester, which is expected because the logs are less crisscrossed in the process of felling and cross-cutting, and consequently it takes less time to load the forwarder. The difference is small though and amounts to 5%. The situation is different with the manipulation time (forwarder maneuvering and positioning), i.e. the manipulation time is considerably shorter (about 45%) when technical round wood of soft broadleaves is transported from the felling site where harvester has been used for felling. This is affected by the arrangement of assortments, possibility to form the load from a smaller number of standing points and less need to bypass obstacles. In the opposite case, the forwarder comes across a greater number of high obstacles, which makes the coefficient of obstacle by passing higher and the distance greater. If we look at the structure of downtime, it can be seen that the share of downtime in driving and in loading and unloading is significantly lower in SP2, which can also be attributed to the state of soil and to the arrangement of assortments. Kuitto et al. (1994) outline that the loading time depends on the concentration of wood assortments in a felling site. The share of downtime in unloading is insignificant. The efficiency of the forwarder is evaluated based on the quantification of several factors, which was done, in this case, through a comparative analysis of the basic working norms. The results of this analysis show that the working efficiency of the forwarder was greater in the felling site, where the harvester had been used for felling and cross-cutting. The working efficiency of this vehicle used in the final cuttings of soft broadleaves is similar to the efficiency of different types of forwarders studied in previous researches (Jezdić et al. 1995, Jezdić et al. 1999, Danilović 2010, Danilović et al. 2012a).

On extremely difficult terrains, with low bearing capacity, the movement of the forwarder would be easier if a bogie track was attached. Bogie tracks have never been used in the lowland forests of Vojvodina, so it would be good to determine their impact on the efficiency of forwarders. In the forestry of Finland, bogie tracks are used all the year round, regardless of weather conditions (Suvinen et al. 2006).

In lowland areas, we can make a choice between the tractor and articulated vehicles in the first phase of transporting roundwood. Tractor assemblies are more applicable in favorable terrain conditions since harsh conditions entail low soil bearing capacity and strong presence of shrub vegetation. From a technical aspect, forwarders are better suited for these conditions. The results of this research study show that the average speed of the tractor assembly, made of Same Laser 130 tractor, Imako 12 t trailer and Loglift F61 boom, was by 35.9% higher than the average speed achieved by John Deere 1210E forwarder. It should be emphasized that the conditions were favorable and that hence such results were expected. There was also a difference in the manipulation time, i.e. the time needed to manipulate the forwarder was by 29.6% longer that the time needed to manipulate the tractor assembly.

The forwarder also showed an advantage regarding the time of loading and unloading, since it took 37.6% more time to load the tractor assembly. Concerning the basic working norms, it can be concluded that in the given study conditions, the tractor assembly is an economically more suitable means of transport. Smaller forwarders can be used as an alternative means of transport for thinning operations in the plantations of soft broadleaves. Poršinsky et al. (2011) recommend the use of smaller forwarders in the thinning of hard broadleaves.

7. Conclusions – *Zaključci*

The following conclusions can be reached on the basis of the analysis performed:

⇒ The average driving speed of John Deere 1210E forwarder in the felling site, where the felling was done with a chainsaw, is lower than the average speed in the felling site where a harvester was used for felling and cross-cutting;

⇒ In the same working conditions, a tractor assembly reaches a higher average driving speed than a forwarder;

⇒ The average driving speed of a forwarder on the felling site significantly decreases with an increase in the load volume;

⇒ Loading time decreases with an increase in the log volume and the average loading time per unit is the shortest in the sample plot where felling was carried out by a harvester, while it is the longest if the assortments are transported by a tractor assembly;

⇒ The forwarder manipulation time is significantly shorter in the sample plot where the felling was carried out by a harvester;

⇒ The driving downtime, as well as the loading and unloading downtime, is the shortest in the sample plot where the felling was carried out by a harvester;

⇒ Under the study conditions, tractor assemblies are more convenient from the economical point of view.

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Sažetak

Transport tehničke oblovine pomoću forvardera i traktorske ekipaže iz topolovih plantaža

Članak je rezultat istraživanja radne učinkovitosti forvardera i traktorske ekipaže na području odabranih pokusnih ploha u topolovim plantažama, u kojima su primijenjene različite metode rada pri sječi i izradi drva. Osnovni je cilj rada istražiti utjecaj rasporeda drvnih sortimenata na brzinu kretanja sredstva za privlačenje drva, na vrijeme potrebno za utovar i rukovanje (manevriranje) sredstvom za rad te na ukupni radni učinak sredstva za rad. Istraživanje je provedeno u Vojvodini na području poduzeća »Vojvodina šume«. Ukupno je snimljeno 170 ciklusa i izvezeno 2 166,73 m^3 tehničke oblovine. Rezultati istraživanja pokazuju da se forvarder brže kreće na radilištu gdje se sječa i izrada obavljaju pomoću harvestera. Brzina kretanja sredstva za rad bila je 10 % veća, a utovar forvardera trajao je 5 % manje vremena. Dobivene razlike znatno su veće vezano uz vrijeme rukovanja (manevriranja i pozicioniranja) sredstva za rad tijekom utovara drva. Brzina kretanja smanjuje se povećanjem obujma tovara, a niža potrošnja goriva utvrđena je na radilištima gdje su sječa i izrada obavljene harvesterom. Pri istim uvjetima rada traktorska ekipaža postiže bolju proizvodnost zato što postiže *pri kretanju značajno veću brzinu. Razlike u prosječnom obujmu tovara nisu bile tako velike, što značajno utječe na proizvodnost traktorske ekipaže. Istraživanjem je potvrđena početna teza da forvarder ostvaruje veći radni učinak na radilištima na kojima su sječa i izrada drva provedene harvesterom.*

Ključne riječi: forvarder John Deere 1210E, traktorska ekipaža, izvoženje drva, tehnička topolova oblovina, učinkovitost, troškovi

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