Productivity Models for Operational Planning of Timber Forwarding in Croatia

Igor Stankić, Tomislav Poršinsky, Željko Tomašić, Ivica Tonković, Marko Frntić

Abstract – Nacrtak

In the area of Croatian lowland forests, forwarders are usually used for extraction of timber assortments. Within the project »Systematization of norms for the production of timber assortments«, which was financed by the state company »Hrvatske šume« d.o.o. (»Croatian Forests«), the process of development and implementation of new productivity norms for forwarders was carried out.

Initially, for the execution of the research, it was necessary to gather data about technical characteristics of forwarders most frequently used in Croatia, but also around the world. The morphological analysis was performed and it was the basis for the classification of forwarders into classes. Three classes of forwarders were obtained after cluster analysis and load capacity appeared to be the most important factor. Machine performance was evaluated on 30 research sites. The standard method of time study (snap-back chronometric technique) was used. During the recording process, data of factors influencing forwarding (stand and terrain conditions) were collected.

After analyzing the collected data, it was determined that the forwarding productivity depends on the forwarder class, average extraction distance, load characteristics, terrain and stand conditions. Regression analysis was used for identifying the time consumption of individual work components, and the productivity model for forwarding was developed.

The obtained model was implemented into the application HsPPI. This is a part of the information system developed by IT Department of the state enterprise »Hrvatske šume« d.o.o. and is used for production planning in timber harvesting. The system is based on dBase IV databases and two main program modules. The main parts of the system are: tree marking data, assortment structure plan, production plan (felling, processing and extraction) and sales plan. Within a part of the production plan there is a module for calculating productivity norms for timber forwarding.

Keywords: forwarder; productivity norms; planning; lowland forests, Croatia

1. Introduction – *Uvod*

In the Republic of Croatia, state forests and forestland cover an area of 2,106,917 ha and most of them (96%) are managed by the state enterprise »Hrvatske šume« d.o.o. (»*Croatian Forests*«; HŠ; Anon 2006). From the economic aspect, selection and even-aged forests are the most significant forests of high silvicultural form. In the Republic of Croatia timber extraction is mainly mechanized, while felling and processing is motor-manual and carried out by chainsaws (Bojanin and Krpan 1997). In Croatian mountainous selection forests, skidders are used for timber extraction (Sabo and Poršinsky 2005). On the other hand, in cases of even-aged forests in hilly and lowland areas, depending on the stand and terrain conditions, skidders and forwarders are used for timber extraction, while the use of adapted farming tractors and tractor assemblies has decreased (Krpan 1996; Beuk et al. 2007). The lowland area of forests and forestland owned by the state amounts to something more than 322 thousand ha (Pentek et al. 2011). The lowland forests are of particular importance for this research, as forwarders are mainly used in this part of Croatia. Lowland forests consist of forest stands of the pedunculate oak (*Quercus robur* L.), narrow-leaved ash (*Fraxinus angustifolia* Vahl.), black alder (*Alnus glutinosa* [L.] Gaertn.), willows (*Salix* sp.), poplars (*Populus alba* L., *Populus x euramericana* clones) and common hornbeam (*Carpinus betulus* L.). Annual removal

amounts to more than 1 mill m³ of wood (Anon 2011). The figures might not be impressive; however, wood from these forests (pedunculate oak) has been achieving high prices on the roundwood market, which is where the importance of the lowland forests can be seen at its best. The aim of this research is to establish the system of planning timber extraction from late thinning and shelterwood felling of lowland forests in Croatia.

2. Problematics – *Problematika*

Forwarders are self-propelled vehicles intended for the transport of trees and their parts loaded in the vehicle bunk area (ISO 2009). The development of the first forwarder started in Sweden around 1950s, and their use in Croatia started in 1971 (Slabak 1983). Forwarders were originally used in cut-to-length timber harvesting, where the felling of trees was performed by harvester, and extracting by forwarder. In Croatian forestry forwarders are mostly used in lowland forests, particularly for the extraction of timber from shelterwood felling and late thinning (Poršinsky 2002). Therefore, for investigating forwarders' performance in Croatia, the lowland forests are the most significant as they cover almost 25% of the total area covered with high forests (Krpan 1996). Secondary (technical) productivity in forestry is significant for the research of forest operations (Löffler 1989). From a scientific point of view, the research of forest operations includes the study of timber harvesting, ergonomics, mechanization, construction, economic aspect and planning of operations, all within the framework of a sustainable forestry development (Samset 1992). The research of forestry operations, and hence also timber forwarding, is based on time study and on monitoring the influencing (quality and quantity) factors, data analysis, and mathematical modeling of time consumption of individual components of the working process (Samset 1990). Similarly as other forms of timber extraction, forwarding also has the characteristics of a cyclic working process.

Forwarder efficiency is affected by numerous factors. The most important factors influencing the efficiency of timber forwarding is the travel distance (Sever 1988). With the increase of the travel distance, the impact of the load volume on the vehicle productivity is also increased (Raymond 1989). Apart from the forwarding distance, productivity is also affected by the average assortment volume (number of pieces in the load) and quantity of timber on a felling site, which is more pronounced in thinning stands (Tufts and Brinker 1993; Tufts 1997). The highest share of time consumption in forwarder operations is related to the so-called terminal times, and namely loading and unloading of timber (Minette et al. 2004). Optimization of load volume and forwarding distance, and giving preference to downhill forwarding are the key factors for improving the productivity of forwarders (Tiernan et al. 2004). Terrain slope higher than 30% considerably decreases the productivity of forwarders because on such terrains vehicle mobility is limited (Zimbalatti and Proto 2010). Terrain classification aimed at determining the optimum machine for timber extraction shows that in hilly-mountainous area, too, the share of timber forwarding is quite considerable (Mihelič and Krč 2008; Pentek et al. 2008). On steep terrain, up to 60%, it is possible to use forwarders with winch, the so-called cable forwarders (Kühmaier and Stampfer 2010). The use of semi-tracks in conditions of limited soil bearing strength increases fuel consumption but provides vehicle mobility (Wästerlund et al. 2011). Apart from travel distance, load volume and terrain conditions, forwarder productivity is also affected by the type of felling, length and type of assortment, driver's skill and knowledge, as well as characteristics of hydraulic crane and vehicle load space (White 2004). The increase of the average assortment volume and terrain slope in travel direction (downhill forwarding) result in the decrease of time consumption (Ghaffarian et al. 2006). The density of secondary forest roads (forest trails) also affects the forwarding productivity (Mederski 2006). Up to date planning methods, i.e. spatial optimization of working cycle shifts based on data on quantity and locations of assortments and possible travel areas of the felling site also increase the timber forwarding productivity (Flisberg et al. 2007). Comparative research of skidding/forwarding machines carried out in stands of small coniferous trees showed that, in terms of costs, figures speak in favour of timber forwarding, as forwarder productivity is twice higher than the productivity of the skidder with winch (Li et al. 2006). Forwarder efficiency depends on the type of the vehicle used, i.e. on its nominal carrying capacity, as forwarders of higher carrying capacity achieve lower costs and higher productivity per product unit (Jiroušek et al. 2007). Nowadays forwarders are not conceptually different from those of half a century ago, but they have made serious progress in terms of environmental soundness, ergonomics and steering automation (Pandur et al. 2009). One of the ways to increase productivity is the use of dynamic system for changing the volume of the bunk area (Brunberg 1999), i.e. its height and width (Brunberg 2001). Attaching the trailer with the loading space behind the rear end of the standard forwarder may increase the system productivity (Lindroos and Wasterlund 2011). Investigations were performed of the use of »flats« or »swop bodies«, where timber is not unloaded

from the forwarder nor loaded into the truck, as they are used with both kinds of transport, thus increasing productivity and simplifying primary transport of timber, but with increased costs (Freitag and Warkotsch 2011). Considering the productivity and costs of timber harvesting machines at an annual level, the share of the travel of machines between felling units is quite considerable, so when planning, the possibility of leasing trucks for the transport of machines should be taken into account (Väätäinen et al. 2006).

Productivity of timber forwarding is higher than the productivity of timber skidding in lowland forests of Croatia, and the increase depends on stand and terrain conditions and ranges between 28 and 126% (Bojanin and Krpan 1994). The operation of forwarders in Croatia, unlike the Scandinavian assortment method (CTL), makes no use of felling and processing machines. This is the effect of natural factors (natural forests, trees of large size, considerable share of broadleaved trees, etc.), but also of tradition (Bojanin and Krpan 1997). The above said is the cause of a different approach to gathering and processing data, selecting the influencing factors and modelling the working process. One of the problems arising is the definition and determination of the mean distance of timber forwarding. Some authors consider that the distance of timber forwarding is the distance between the roadside landing and the point in the felling site when the bunk area is half loaded with timber (Kuitto et al. 1994; Nurminen et al. 2006). Accordingly, the mean distance of timber forwarding would be equal to the sum of travel distance of unloaded vehicle and half the travel in timber loading i.e. the travel between the loading points (Suvinen 2006; Väkevä et al. 2001). When investigating forwarders in Croatian lowland forests, the distance of timber forwarding was considered to be the arithmetic mean of the sum of distances travelled by fully loaded and unloaded forwarder, while the time consumption of the vehicle movement during loading process was defined depending on felling density, i.e. net timber volume per hectare (Poršinsky 2002, 2005; Stankić 2010).

Fig. 1 Forwarding in Croatian lowland forests
Slika 1. *Izvoženje drva u hrvatskim nizinskim šumama*

The production of timber assortments has been supported by information systems used by the state company HŠ for monitoring and recording the production of timber assortments. The information system has been continuously developing for twenty years, since the founding of the company, and it is the result of the development program of the company's IT Department. At the beginning of the development, the system was based on personal computers with programs made in computer language FoxPro 2.6 for DOS (dBase IV as database). Although the computerization of the company has gone a long way from those times, a part of these programs and FoxPro2.6 as program language are still being used, while new programs are being developed for Windows operating systems in Visual FoxPro 9.0 and on.NET platform with MS SQL database.

A part of the information system of the company HŠ is the production subsystem, by which all timber harvesting processes are monitored – from production planning to issuing bills to buyers. *HsPPI* and *HsPro* are important parts of this subsystem. *HsPPI* refers to the production planning, while *HsPro* refers to the monitoring of timber assortments production.

The basis of the information flow is in the forest database *HsFond* that basically represents digitalized Management Plan Prescriptions. One of the factors is the Harvesting Plan, which represents the beginning of the production planning. On that basis, the harvesting (sub)compartment is selected, tree marking data is prepared, distribution of marked trees is entered, harvest is planned out, cut block is established, the technology of timber processing is chosen along with the production plans, where the felling and processing norms, as well as the primary transport, have to be determined. At the end of the planning process, the sales plan is developed. All these processes are carried out within the *HsPPI* application that HŠ uses for the preparation of production within harvesting.

3. Materials and methods – *Materijal i metode*

3.1 Classification of forwarders – *Razredba forvardera*

A good knowledge of forwarders as means of work in the forestry production is of crucial significance. Many research methods are already known,

Table 1 Some technical features of investigated forwarders
Tablica 1. *Neke tehničke značajke istraživanih forvardera*

Forwarder type *Tip forvardera*	Number of wheels *Broj kotača*	Engine power *Snaga motora*	Length *Duljina*	Width *Širina*	Height *Visina*	Mass *Masa*	Payload *Nosivost*	Crane reach *Dohvat dizalice*
	n	kW	mm	mm	mm	kg	kg	m
Timberjack 1210	6	114	9,060	2,640	3,710	11,720	12,000	10.3
Timberjack 1410B	8	129	9,205	2,705	3,700	16,500	14,000	8.5
Timberjack 1710B	6	156.5	10,450	3,010	3,900	17,400	17,000	7.2
Valmet 840	6	124	9,007	2,650	3,780	13,800	12,000	9.2
Valmet 860	6	140	9,170	2,740	3,789	14,300	14,000	9.2

from those that determine borderline usability, to those that study the historical development of its construction. One of the studying methods for the machines used in forestry is the morphological analysis based on the selected geometrical, mass and other factors, on which basis dependencies are calculated and opinion on validity of machine selection is made (Poršinsky 1997). One of the first morphological analyses of off-road vehicles was carried out by Bekker in 1956 (Sever 1980). Gradually, the method was accepted and is used even today for the evaluation of forestry machines or tools, especially by researchers from Department of forest engineering of the Forestry Faculty Zagreb for investigation of chippers (Šušnjar 1998), farming tractors (Horvat and Šušnjar 2001), skidders (Horvat et al. 2007), hydraulic cranes (Šušnjar et al. 2007), chainsaws (Poršinsky et al. 2008), farmer winches (Šušnjar and Borić 2008).

In the Croatian forestry, the following forwarders are used most frequently: Timberjack 1210, Timberjack 1410, Timberjack 1710, Valmet 840 and Valmet 860 (Table 1). Modeling of productivity individually for each forwarder would be cost-ineffective, so it was necessary to group them in classes and analyze them on that basis. Many forwarder classifications are already known, and according to them forwarders are classified by net mass, load capacity or gross mass (vehicle + load, (Poršinsky 1997)). The latest forwarder classification found in literature is made based on their loading capacity (payload) to light (<10 t), medium (10 t – 14 t) and heavy forwarders with the load capacity over 14 t (Brunberg 2004). In this case, the morphological analysis of forwarder families according to their numerical values (dimensions, mass, load capacity, etc.) will be used as a basis for grouping vehicles in classes. The data have taken from the obtained and adapted database, only for the vehicles of the new generation (Lugmayr et al. 2009).

3.2 Assortments characteristics – *Značajke sortimenata*

The Croatian lowland forests are characterized by a great variety of stand conditions. There is a wide range of tree species, from willows and poplars, over black alder and narrow-leaved ash, to pedunculate oak and common hornbeam. The area is characteristic by the assortment method of processing, with forwarding as a special way of timber extraction. The assortment volume is important for obtaining the correct figures of the mean load volume that impact the forwarder productivity. The aim was to obtain the mean assortment dimension, so it was formed on the basis of trees taken from the tree marking data, that is by connecting the data from two applications of the information production subsystem *HsPPI* and *HsPro*. Data on trees marked to be felled and data on processed timber assortments in the work yards were collected for the yards where the extraction has been carried out with forwarders over the last couple of years (Fig. 2). Data on tree species whose share in the lowlands is low (fruit trees, common maple, lowland elm, walnut, etc.) were left out from the analysis, as well as cutting blocks with small number of samples. Only the data for the most important species, based on their share in the prescribed removal of the Croatian lowland forests, were taken into analysis: pedunculate oak, common hornbeam, narrow-leaved ash and black alder. The goal of the analysis is to determine the mean assortment volume, mean diameter and length from the volume of marked tree by the tree species. The stated is necessary to determine the productivity of forwarders in this system of harvesting.

3.3 Forwarder productivity – *Proizvodnost forvardera*

The research of forwarder productivity was carried out in the area of Croatian lowland forests (Fig. 2). In this research, the term Object of Study (OS) is

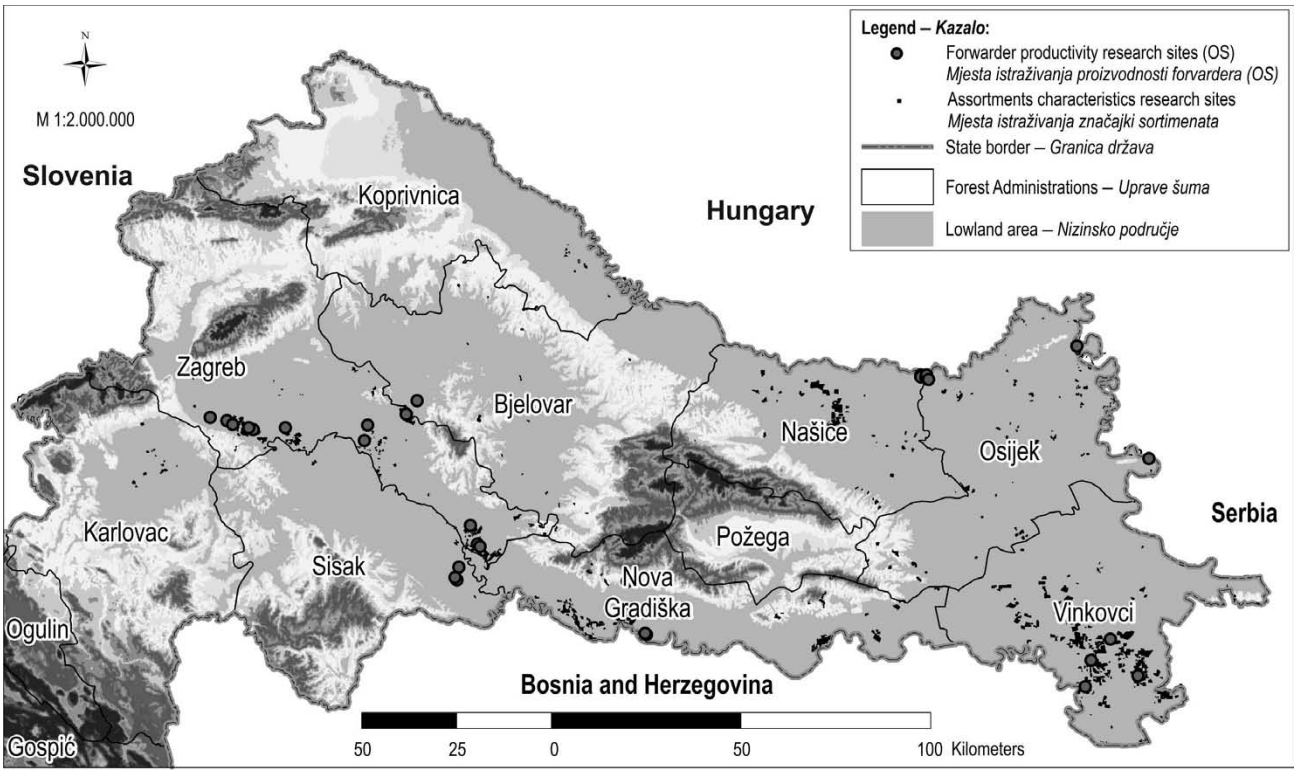

Fig. 2 Research sites of forwarder productivity and timber assortments characteristics
Slika 2. *Mjesta istraživanja proizvodnosti forvardera i značajki sortimenata*

used, which refers to individual stand, that is the compartment/subcompartment where harvesting is carried out. Raw data for productivity analysis were taken from the previous investigations of a total of 30 objects; 5 OS (Poršinsky 2000) + 3 OS (Poršinsky 2005) + 22 OS (Stankić 2010). Average removal per OS was 199.79 m^3/ha, average tree size was 3.22 m^3/tree and average area of OS was 27.70 ha.

The research of the machine work is based on the time and work study. The basis is the work and time study, division of work process or work phase into consisting parts of the shortest possible time duration that can still be measured precisely enough. Contemporary approach to time study presupposes the implementation of analytical measuring methods, whereby work process is divided under particular schemes into work components with the goal of synthesis during data and results processing.

Extraction of timber by forwarders has the characteristics of cyclic work. Each cycle (turn) consists of four main cyclic work components (unloaded traveling, timber loading, loaded traveling and unloading of timber), plus work pauses or time consumptions whose character is not cyclic, but periodic.

Forwarder productivity is modeled by the following module:

$$t = f_a \left\{ s_{of} \cdot \left(\frac{60}{v_1} + \frac{60}{v_2} \right) + s_{on} \cdot \left(\frac{60}{v_3} + \frac{60}{v_4} \right) + t_l + t_u \right\} \left[\frac{\min}{turn} \right]$$

$$P = \frac{60 \cdot V_l}{t} \left[\frac{m^3}{h} \right]$$

where:

t – total time, min/turn
s_{of} – forwarding distance (offroad), km
v_1 – unloaded vehicle speed (offroad), km/h
v_2 – loaded vehicle speed (offroad), km/h
s_{on} – forwarding distance (forest road), km
v_3 – unloaded vehicle speed (forest road), km/h
v_4 – loaded vehicle speed (forest road), km/h
t_l – loading time, min/turn ($t_l = t_{l1} + t_{l2}$)
t_u – unloading time, min/turn ($t_u = t_{u1} + t_{u2}$)
f_a – additional time factor
V_l – load volume, m^3/turn
P – productivity, m^3/h

The study of forwarder work time was carried out by snapback method, using manual digital chronometer. Besides the time study, data were collected of all factors influencing the work process. Forwarding distance was measured by hand GPS devices. In order to establish the forwarder performance, loaded

Table 2 Correlation table of studied values (those bold are significant at $p < 0.05$)
Tablica 2. *Korelacijska tablica proučavanih vrijednosti (podebljane su signifikantne za* $p < 0,05$*)*

Characteristics *Značajke*	Means *Artimetičke sredine*	Std. Dev. *Standardne devijacije*	Engine power *Snaga motora*	Length *Duljina*	Width *Širina*	Height *Visina*	Clearance *Odignutost vozila od podloge*	Mass *Masa*	Payload *Nosivost*	Crane reach *Doseg dizalice*	Lifting moment (gross) *Bruto podizni moment dizalice*
Engine power, kW *Snaga motora, kW*	138.24	28.51	1.00	0.60	0.72	0.53	0.53	0.82	**0.81**	**0.08**	0.79
Length, mm *Duljina, mm*	9,314.38	874.15	**0.60**	**1.00**	**0.63**	**0.32**	**0.60**	**0.66**	**0.67**	-0.02	**0.67**
Width, mm *Širina, mm*	2,716.63	170.42	**0.72**	**0.63**	1.00	0.59	0.47	0.80	0.84	**0.12**	0.82
Height, mm *Visina, mm*	3,710.45	133.33	**0.53**	**0.32**	**0.59**	**1.00**	**0.34**	**0.64**	**0.65**	0.35	**0.70**
Clearance, mm *Odignutost vozila od podloge, mm*	637.36	57.64	**0.53**	**0.60**	**0.47**	**0.34**	1.00	0.58	0.60	-0.08	0.61
Mass, kg *Masa, kg*	15,183.75	3,038.63	**0.82**	**0.66**	**0.80**	**0.64**	**0.58**	**1.00**	**0.85**	0.11	**0.84**
Payload, kg *Nosivost, kg*	12,672.46	2,702.39	**0.81**	**0.67**	**0.84**	**0.65**	**0.60**	**0.85**	1.00	0.12	0.89
Crane reach, m *Doseg dizalice, m*	8.88	1.21	0.08	-0.02	0.12	**0.35**	**–0.08**	**0.11**	**0.12**	**1.00**	**0.27**
Lifting moment (gross), kN *Bruto podizni moment dizalice, kN*	107.10	24.42	**0.79**	**0.67**	**0.82**	**0.70**	**0.61**	**0.84**	**0.89**	0.27	1.00

assortments were counted and the number of the identification plastic tag was recorded in case of large sawtimber and veneer assortments. In other cases (with small assortments – pulpwood and long firewood), direct measurement of processed assortments took place, whereby data on tree species, mean diameter and length were entered into a corresponding form. The ground bearing capacity was determined for each individual cycle, by visual estimate of the recorder. The soil bearing capacity was studied in line with the modified classification of ground bearing capacity that was already used in similar form within the research of machine performance in areas of the Croatian lowland forests (Poršinsky 2000). Under this classification, forest soils were classified into the following load-bearing groups, and it was applied in further analyses:

⇒ Soil of good load-bearing capacity – firm and moderately firm soil. It includes dry, frozen or occasionally wet soil which presents no problems for moving vehicles. By a single pass of the vehicle, the tracks depth amounts to less than 5 cm, and by multiple passes the depth amounts up to 25 cm, maximum 30 cm. When walking on such soil, shoe soles are dry or humid.

⇒ Soil of limited load-bearing capacity – soft and very soft soil. It is a soil that is partly to fully saturated with water. Walking on it is difficult, tracks of shoes are fully visible. Sinking of vehicles into the ground and slipping of wheels are appeared, vehicle speed is reduced, and after a single pass, the mineral layer of the soil can be exposed. Implementation of semi-tracks on the rear wheels of bogie axle and chains on the front wheels of single axle is recommended to obligatory (in extremely unfavorable conditions).

Before starting the recording, an online form for the input of recorded data was developed. The form was developed using.NET technology and it could be found at the address http://norme.hrsume.hr. At the end of the work process recording, each recorder would register to the stated webpage and enter the data into the integral database. MSSQL database was used.

4. Results of the research – *Rezultati istraživanja*

4.1 Forwarder classification – *Razredba forvardera*

Forwarder analysis was carried out in the program package Statistica 08. In this analysis, the following vehicle morphological values were used: length, width, height to the cab roof, clearance of the vehicle from the ground, mass, payload, reach and lifting moment of the hydraulic crane. For the values whose data were not available in the established database, substitution was made with the value of the arithmetic mean of that variable. Database contains variables for 56 forwarders. Through a thorough consideration of the effect of available data on morphological characteristics of vehicles, the connection of the vehicle mass with most other values is evident (Table 2), which is logical due to the fact that the existence of mass determines the occurrence of other features. Vehicle mass is mostly correlated to the power of the engine and to payload and it is the key parameter, on which all other forwarder characteristics, except the hydraulic crane reach, are dependent. If the mass value increases, all other vehicle characteristics increase, too.

Payload (PL, load capacity) is one of the most important exploitation characteristics of forwarders. By reviewing the vehicles' technical characteristics database it can be determined that mass and load capacity of forwarders are approximately the same. The highest correlation to other values is indicated precisely by the PL of the vehicle (Table 2). For this reason, PL was used for the classification of forwarders.

The k-mean algorithm was used for grouping of forwarders. This algorithm assigns each item to the group whose centroid is closest to it. Centroid is a point created by calculating the arithmetic mean for each dimension, separately for each item in the group. By implementing the mentioned algorithm, grouping of data into groups based on PL was made. The first group includes forwarders whose PL is closest to the centroid of 9,929 kg. The second group includes those whose PL is closest to the centroid value of 12,125 kg, while the third group is formed by forwarders whose PL is closest to the value of 15,571 kg. Distribution of variables, payload and other technical features according to forwarder class are shown in Fig. 3.

Through further analysis for the needs of operative classification of forwarders, rough borderlines can be set among three forwarder classes by their PL, and those are: 11,000 kg and 14,000 kg. The first class consists of vehicles whose PL is less than 11,000 kg, the second of those whose PL amounts from 11,000 to 14,000 kg, while the third class consists of forwarders whose PL is above 14,000 kg.

As it is obvious that the increase of PL in the forwarder family results in the increase of other studied dimensions, it can be concluded that there are three forwarder classes – light, medium and heavy forwarders. In line with the performed classification it can be determined that light forwarders are not used in the Croatian forestry. Therefore further research will be focused on the medium and heavy forwarders. Timberjack 1210 and Valmet 840 fall into the class of medium forwarders, whereas Timberjack 1410, Timberjack 1710 and Valmet 860 are in the class of heavy forwarders.

4.2 Characteristics of assortments and vehicle load – *Značajke sortimenata i tovara forvardera*

In order to gain insight into the load characteristics (mean volume and mean diameter), data from 1532 working sites were analysed, where timber extraction was carried out by forwarders over the last few years (since the beginning of full implementation of information production subsystem *HsPPI* and *HsPro*). Work sites were situated in the area of the Croatian lowland forests, and they are characterized by motor-manual felling and assortment method of timber processing along with the timber extraction by forwarders. Each point in Fig. 4 represents average value for individual felling site.

Two groups of assortment size can be detected (Fig. 4). The first group is formed by the classes of large assortments of bigger dimensions – veneer logs, sawlogs (1^{st}, 2^{nd} and 3^{rd} class) and logs for peeling. The second group includes small assortments, usually of smaller dimensions – long firewood, mining wood and thin industrial roundwood. Both assortment groups show a large dissipation of raw data, which is a consequence of buck-to-quality (BTQ) and assortment method of timber processing.

Dependence of the number of loaded assortments on the decrease of soil bearing capacity has been determined (Fig. 5). By decrease of soil bearing capacity, the number of loaded roundwood assortments is reduced as well. In some cases, the overload of forwarder was noticed in conditions of limited soil bearing capacity, aimed at increasing productivity in spite of the decrease of vehicle speed. This can be explained by the subjective influence of some forwarder operators and their overloading of the vehicle in unfavourable conditions, all with the goal of increasing the work efficiency. Reduction of load-

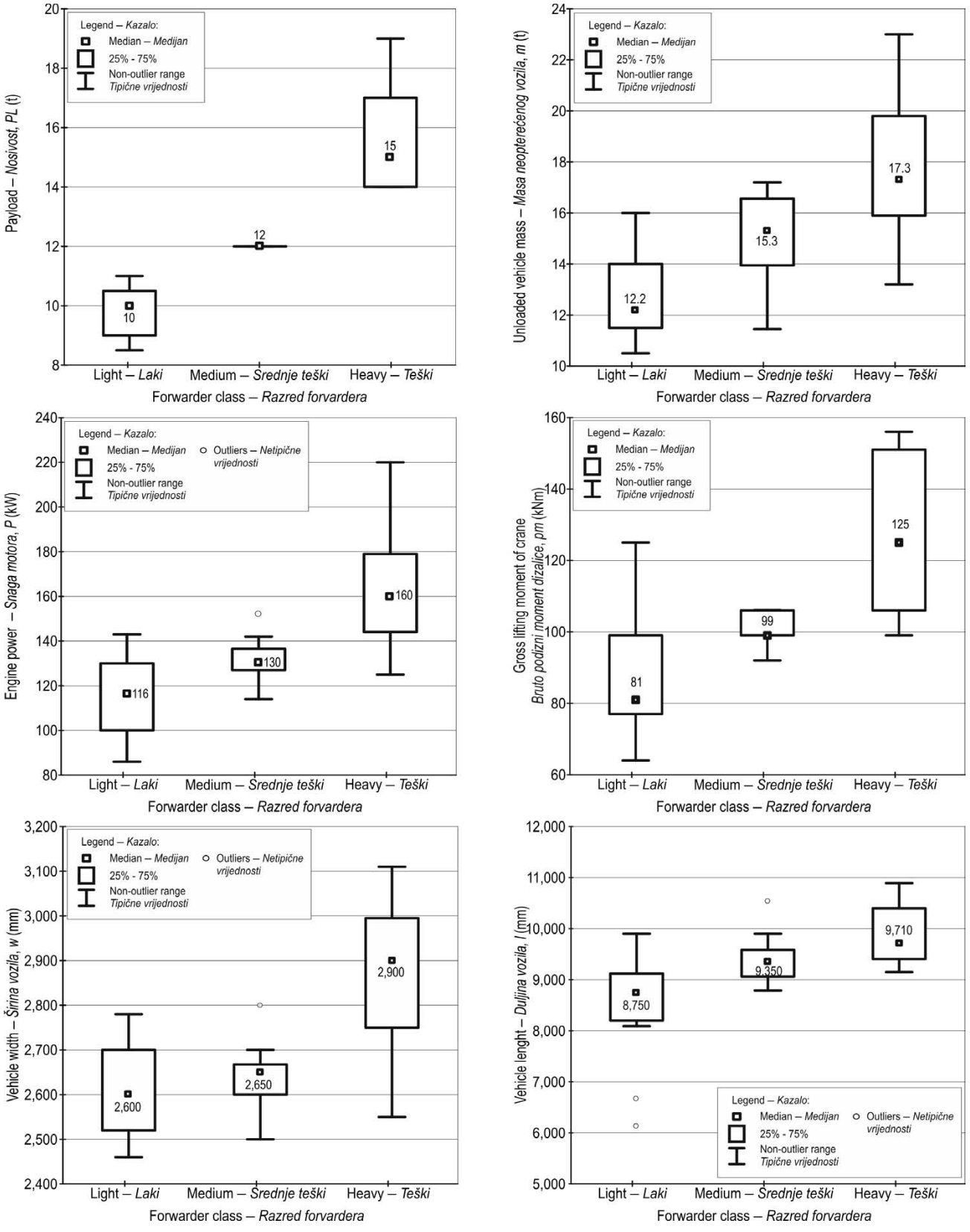

Fig. 3 Some technical features according to forwarder class
Slika 3. *Neke tehničke značajke pojedinih razreda forvardera*

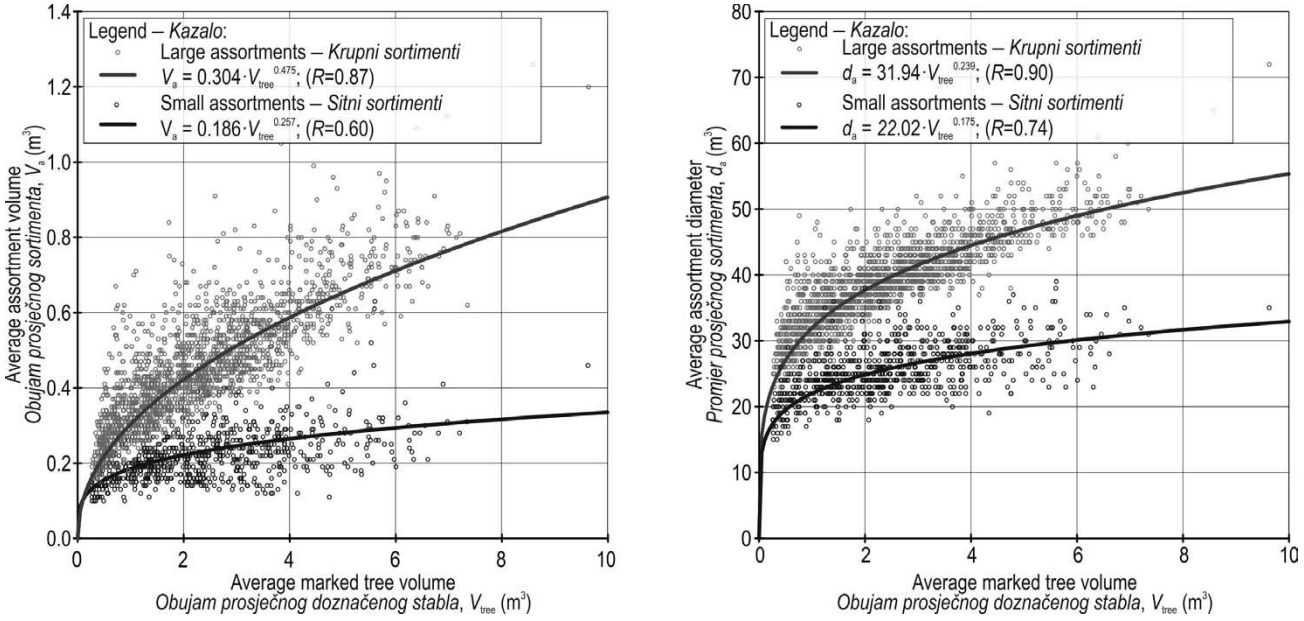

Fig. 4 Characteristics of roundwood from Croatian lowland forests
Slika 4. *Značajke oblovine iz hrvatskih nizinskih šuma*

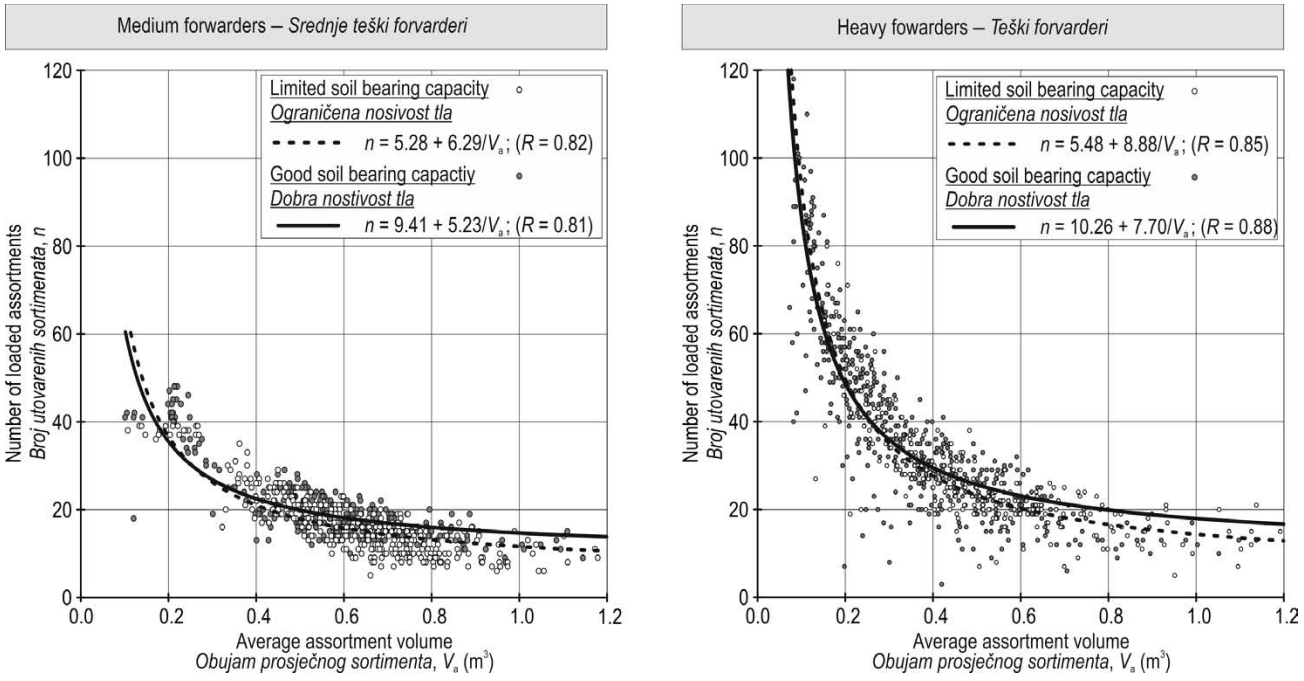

Fig. 5 Number of roundwood pieces in the bunk area of forwarder
Slika 5. *Broj komada oblovine u tovarnom prostoru forvardera*

ed assortments in conditions of reduced soil bearing capacity was more expressed with the large than with the medium size forwarders.

The analysis that was carried out, i.e. the modelling of the mean assortment volume, is the input indicator for determining further load characteristics. One of the most important parameters is also the number of loaded assortments (Fig. 5). The product of mean assortment volume and number of assortments gives the load volume ($V_l = V_a \cdot n$).

4.3 Modeling of the forwarder productivity
Oblikovanje proizvodnosti forvardera

The forwarding productivity was studied using the time study on totally 1440 recorded work cycles, out of which 651 cycles were performed with medium, and 789 with heavy forwarders.

4.3.1 Time consumption of loaded and unloaded vehicle travel – *Utrošak vremena vožnji opterećenoga i neopterećenoga vozila*

Based on the dependence of time on the travel distance, the average speed of (un)loaded forwarders on forest road and off-road was calculated. The assumption was that forwarders move at uniform speed (Fig. 6). Medium size forwarders have a better mobility in the conditions of limited soil bearing capacity than heavy forwarders when they are unloaded. This is not the case in the conditions of good soil bearing capacity where heavy forwarders reach higher speeds. Larger differences in the vehicle speeds on the forest road between the forwarder classes are caused by bigger variety of conditions on the monitored sites in the areas of roadside landings.

Based on the modeled driving speeds (arithmetic means of recorded speeds per turn, Fig. 6) of forwarders and average traveling distances off-road (s_{of}) and on the forest road (s_{on}), time consumption of a traveling is obtained.

4.3.2 Time consumption of timber loading
Utrošak vremena utovara drva

Timber loading time covers the time of forwarder's work in the felling area during loading, and the characteristic of this variable is that it does not change with the change of the forwarding distance. Forwarder's work in the felling area starts with the end of the unloaded vehicle travel, or in other words, on the spot of the first loading. After loading the processed assortments within the reach of the hydraulic crane, the forwarder moves towards the next loading place, and continues doing so until reaching the optimal load. During timber loading (t_l), two significantly different groups of work components can be detected ($t_l = t_{l1} + t_{l2}$):

⇒ Timber loading with crane (t_{l1}) – the operator loads the timber into the bunk area using only the hydraulic crane,

⇒ Relocation of forwarder (t_{l2}) – forwarder moves from one loading area to the other.

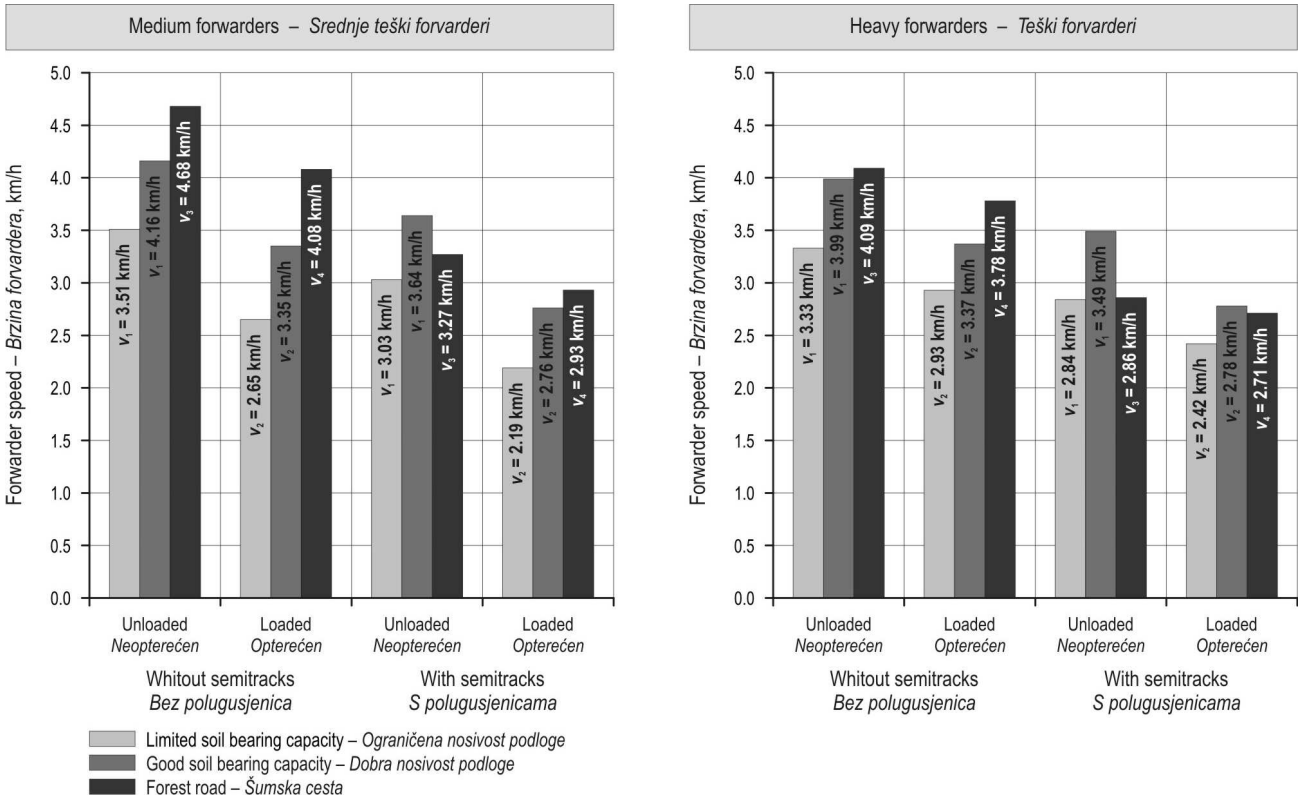

Fig. 6 Forwarders' speed
Slika 6. *Brzine kretanja forvardera*

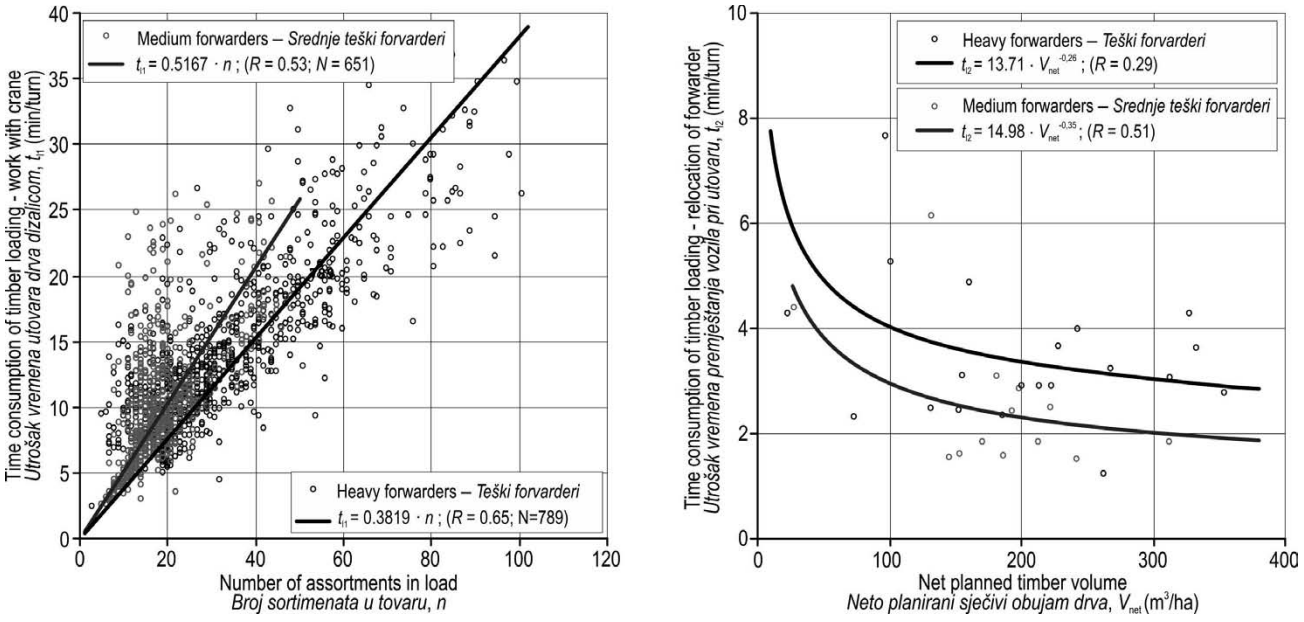

Fig. 7 Time consumption of timber loading
Slika 7. *Utrošak vremena utovara drva*

Time consumption of timber loading by the hydraulic crane is dependent on the forwarder class and the number of loaded assortments. The recorded data are equalized by a linear model line from the source (Fig. 7, left). Timber loading expressed the influence of the »*Volume-Piece Law*«, as the smaller dimensions of the loaded roundwood, the number of loaded pieces and the crane time consumption have increased.

Time consumption of forwarder relocation is impacted by the »*Production Law*«, i.e. by the quantity of the cut and processed timber per unit of area (Fig. 7, right). It is reflected in the exponential increase of time consumption of forwarder relocation due to diminished felling density (thinning) and vice versa (shelterwood and clear cutting). Relocation time consumption is higher within the group of heavy than medium forwarders. This is due to the fact that medium forwarders have larger hydraulic crane reach than heavy forwarders (Table 1).

4.3.3 Time consumption of timber unloading
Utrošak vremena istovara drva

When the loaded forwarder ends its travel, its work starts on the roadside landing aimed at unloading, stacking and sorting of timber. Similar to the loading, the unloading at the roadside landing (t_u) is additionally divided into two groups of work components ($t_u = t_{u1} + t_{u2}$):

⇒ Crane work time (t_{u1}, where the operator works solely with the hydraulic crane with the goal of unloading the timber), and

⇒ Relocation time during unloading (t_{u2}, where the forwarder moves from pile to pile with the goal of separating timber by tree species and quality classes).

Time consumption of crane unloading depends on the forwarder class and number of roundwood in the load. During unloading, the operators classify the timber according to tree species and quality classes, piling the unloaded timber onto separate stacks. The regression curve of recorded data is shown in Fig. 8. The asymptotic model was used. The increase of time consumption of crane unloading with reference to the increase of number of loaded assortments can be observed. It is decreased with the larger number of loaded assortments of smaller mean volume. This is explained by the fact that when unloading, the crane grips two or more pieces of roundwood assortments.

The absence of wood classification and relocation has been noticed on a smaller part of observed research sites. This was conditioned by the stand characteristics (pure stands), silvicultural treatment (type of cutting), type of processing firewood, quality and dimensions of assortments and landing space. In the cases when timber was sorted on the roadside landing, higher time consumption of this work component was recorded. Mean time consumption for heavy forwarders was 0.84 min/turn, whereas for medium forwarders it amounted to 0.73 min/turn (Fig. 8, right). This phenomenon can be explained with the higher initial acceleration of medium forwarders.

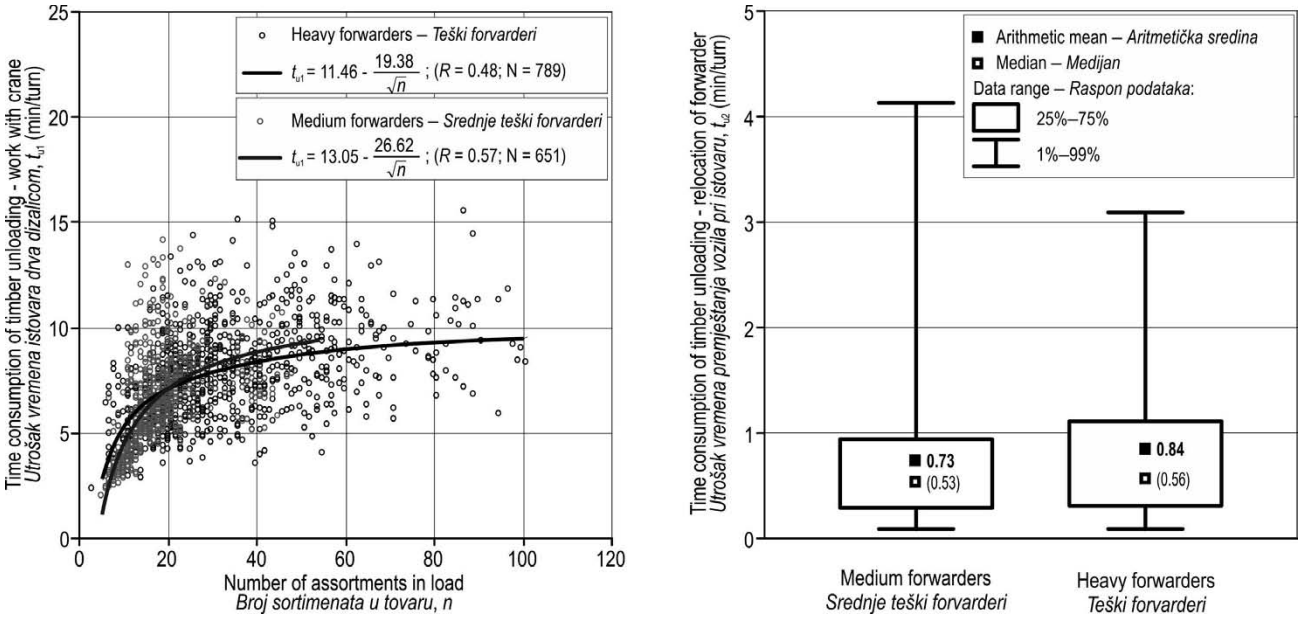

Fig. 8 Time consumption of timber unloading
Slika 8. *Utrošak vremena istovara drva*

The sorting of assortments at the roadside landing has affected the decrease of forwarder efficiency in relation to its efficiency when not performing the timber separation when unloading. By the increase of forwarding distance, the negative effect of timber separation on forwarding efficiency is diminished, due to the growth of vehicle relocating share in the total cycle time.

4.3.4 Delays (downtime) and additional time factors – *Prekidi rada i faktori dodatnoga vremena*

Delays consist of unavoidable and avoidable of work times. Various technological and organizational measures are taken to try and reduce it to the necessary level. The unavoidable delays are classified as preparatory time, occasional works and breaks. The avoidable delays include unnecessary conversations among workers, conversations between workers and passers-by and recorders, and excessive resting time. Vehicle breakdowns that cannot be eliminated without the intervention of a mechanic are also included into the avoidable delays. Avoidable and unavoidable delays per turn were taken into analysis together and they are shown in Fig. 9 (left).

The additional time and additional time factor are determined through the analysis of unavoidable delays only. It was determined by this study that the additional time factors vary in a wide range and that they are higher than in previous studies. The average additional time was determined for each individual OS (Fig. 9, right). The value of the mean additional time factor amounts to 1.33, or 33% of the effective time. Considering the structure of the additional time, it can be determined that the preparatory time accounts for 33%, occasional works for 33%, and personal breaks for 33% of the total unavoidable delays.

5. Implementation of the model into the information system – *Ugrađivanje modela u informacijski sustav*

One of the components of production planning process is the determination of norms for felling and processing, as well as for timber extraction. The existing norms (official and still in use) are inherited from times before the company HŠ was founded (before 1990), and there are still a couple of regional systems functioning.

In order to unify the norm system on the level of the company, »new norms« as a result of work of the Forestry Faculty Zagreb (project bearer) and HŠ (project investor) were created. New norms have been integrated into the *HsPPI* program (Fig. 10). Determination of norms starts with the selection of the management unit (*gospodarska jedinica*) and type of yield (*vrsta prihoda*), followed with the list of the marked compartments/subcompartments from the Management Plan with all the data needed for norm calculation. Those are: type of yield (*prihod*), silvicultural form (*uzgojni oblik*) and total area of the compartment/subcompartment (*površina*). For each compart-

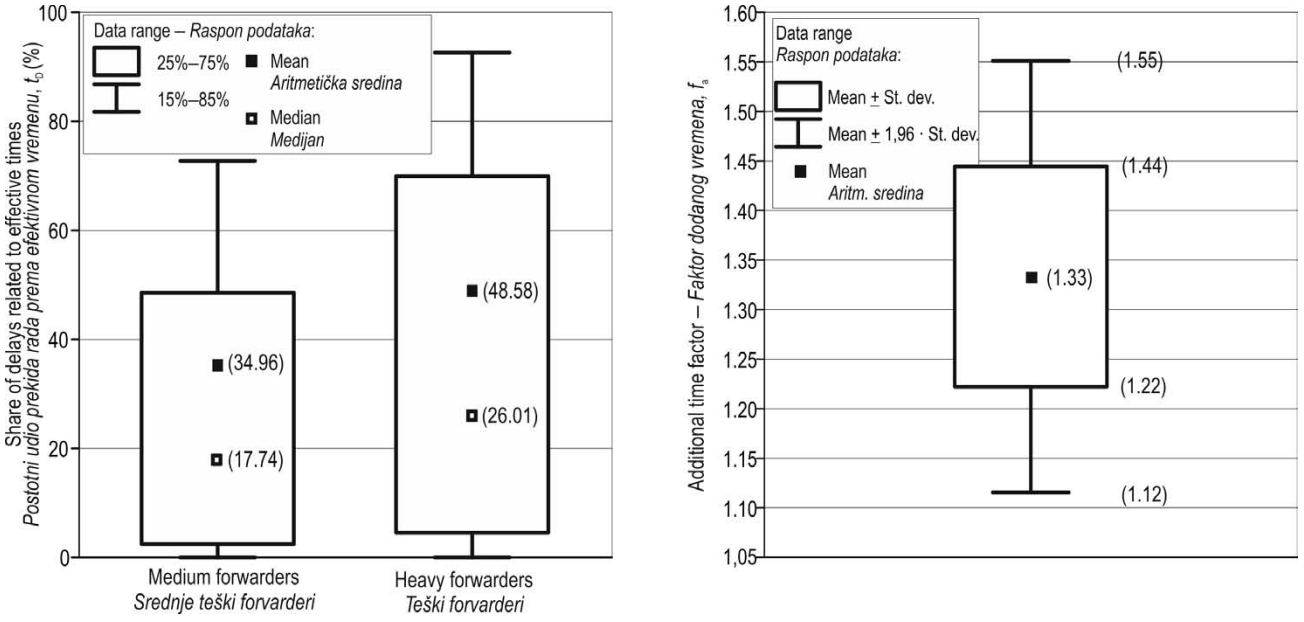

Fig. 9 Share of delays in relation to effective time and additional time factor
Slika 9. *Udjeli prekida rada prema efektivnomu vremenu i faktor dodatnoga vremena*

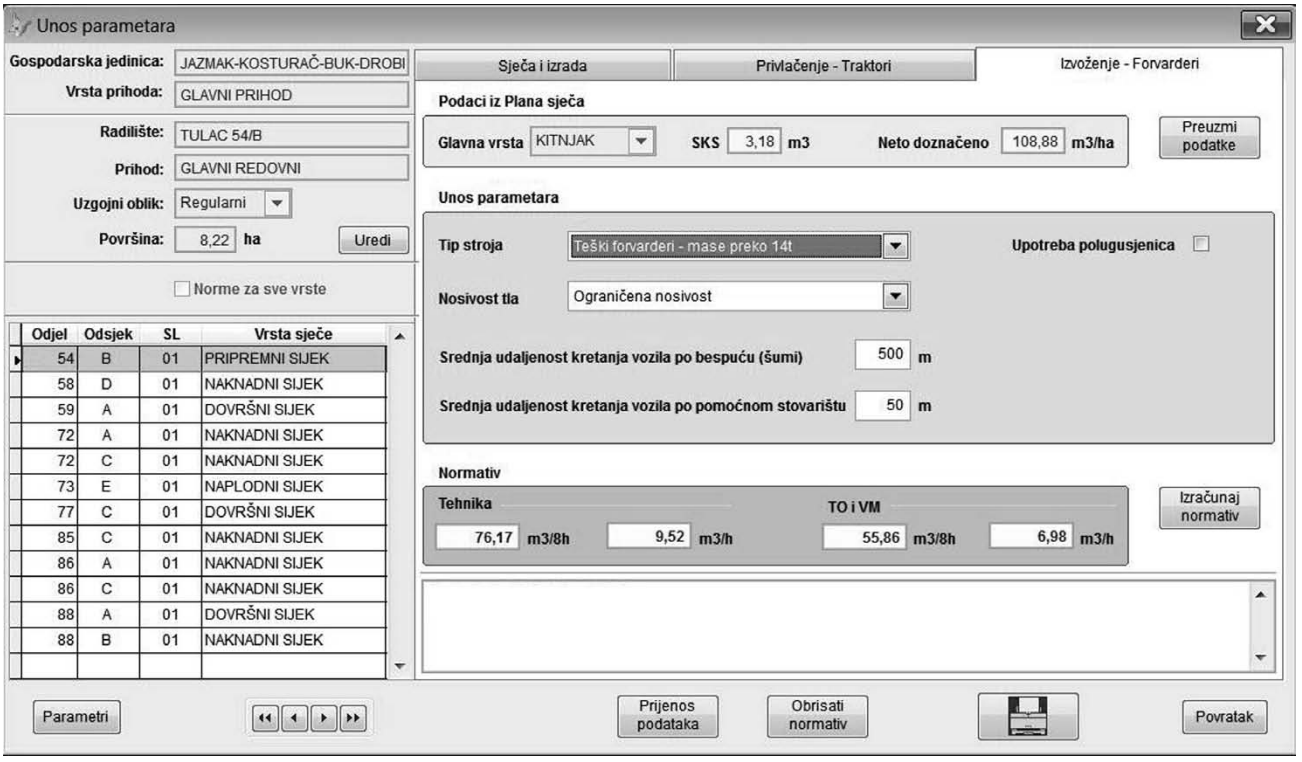

Fig. 10 Screenshot of tab for norm calculation for forwarders in *HsPPI*
Slika 10. *Prikaz zaslona računala pri izračunu normativa za forvardere u aplikaciji HsPPI*

ment/subcompartment from the list there is norm calculated for individual work phase, and this is made by selecting tabs: »Felling and Processing« (*sječa i izrada*), »Extraction – Skidders« (*privlačenje – traktori*) or »Extraction – Forwarders« (*izvoženje – forvarderi*).

The first step in the norm calculation process is the calculation of felling and processing norm, due

to the fact that by selecting the work method, the final assortment structure is obtained, for whose extraction the norm is to be developed. From other data necessary for the development of forwarding norms, a part is taken from the Felling Plan (main tree species – *glavna vrsta*; volume of mean stand tree – *SKS;* net marked wood volume per unit of area – *neto doznačeno*), while other parameters are entered (Fig. 10):

⇒ machine type (*tip stroja*),
⇒ equipped with semi-tracks (*upotreba polugusjenica*),
⇒ soil-bearing capacity (*nosivost tla*),
⇒ mean off-road forwarding distance (*srednja udaljenost kretanja vozila po bespuću*),
⇒ mean forwarding distance on roadside landing (*srednja udaljenost kretanja vozila po pomoćnom stovarištu*).

Output data are norms for large (*tehnika*) and small assortments (*TO i VM*) per hour and per workday (8 hours) for selected work conditions.

Through a thorough analysis carried out by forestry experts it was established that the productivity model presented in this study plans higher norms and decreased delay times than the existing ones (Tomić 2007).

6. Conclusions – *Zaključci*

This research covered the analysis of the factors impacting forwarding, as a special aspect of primary transport of timber in the lowland forests of the Republic of Croatia. It is characteristic of timber harvesting systems in the area that felling is performed motor-manually and timber is processed by power chainsaws, timber is bucked according to its quality, and extraction of timber to roadside landings is fully mechanized. The method used is not the traditional cut-to-length (CTL), but buck-to-quality (BTQ) method.

Aiming to develop an operationally implementable system of timber forwarding planning, forwarders were classified according to their technical characteristics. The most important factor appeared to be the payload, so this variable was used for clustering the vehicle types. Three classes of forwarders were determined: light, medium and heavy forwarders. Light forwarders have a load capacity of up to 11,000 kg, medium from 11,000 kg to 14,000 kg, and heavy forwarders above 14,000 kg. Light forwarders are not used in the Croatian forestry, and farm tractors with semi-trailers equipped with winch and hydraulic crane are used instead.

Loaded roundwood features were determined with the goal of calculating productivity (norm projection) by modeling the volume of large and small assortments from an average marked tree volume for all species represented in the lowland forests. The data were gathered by joining together two information subsystems *HsPro* and *HsPPI*. By the increase of marked tree volume, the average volume of large assortments grows exponentially, whereas with small assortments, after the initial growth, the relations take values closer to the asymptote of the curve (0.34 m^3/pcs).

The results of the forwarding productivity study are under a strong influence of the interaction of important factors prevailing in the Croatian lowland forests, and the study came to the following conclusions:

⇒ The forwarder class influences the level of forwarder productivity, and it does so primarily through its payload, or load volume, but also through its speed and time consumption during loading and unloading.
⇒ Diminished levels of timber extraction by forwarders are influenced by conditions of off-road soil-bearing capacities as a result of the increase of time consumption of forwarding, i.e. lower speed and lower load volume.
⇒ The use of semi-tracks, which provide the mobility of forwarders in unfavorable conditions, additionally lower the speed, increasing the time consumption of forwarding.
⇒ The increase of forwarding distances diminishes forwarder's productivity, as the share of the time spent moving grows within the structure of the total time consumption of the work shift. However, the influence of distance on the forwarding productivity should be viewed through its interaction with the classes of soil-bearing capacity and classes of forwarders. Likewise, with the increase of forwarding distance, the load volume becomes more significant.
⇒ Stand conditions and forest management guidelines demonstrated the impact on the productivity of timber forwarding through the well known *Laws of Mechanizing Forest Works*, i.e. through felling density (*Productivity Law*), features and dimensions of processed roundwood (*Volume-Piece Law* and *Product Type Law*).

Based on the obtained research results and requests of the company HŠ, a model of forwarder productivity for lowland forests was established and finally incorporated into the production information subsystem. Real data from the first planning stage (forest inventory data, tree marking plan, assortment structure plan, etc.) and developed forwarder productivity model, together with input work parameters ensures the objectivity of norms used in timber forwarding.

Acknowledgements – *Zahvala*

The research was conducted with the support of the company »Hrvatske šume« d.o.o. that provided the financial support and insured the material and human resources for the execution of the project *»Systematization of Norms for the Production of Timber Assortments – Norms for Forwarding«*. The project bearer was the Faculty of Forestry of the University of Zagreb.

7. References – *Literatura*

Anon., 2006: Šumskogospodarska osnova područja RH 2006.–2015. (Forest Management Plan, 2006–2015) Hrvatske šume d.o.o., Zagreb.

Anon., 2011: Godišnje poslovno izvješće (Annual account). Hrvatske šume d.o.o., Zagreb.

Beuk, D., Tomašić, Ž., Horvat, D., 2007: Status and development of forest harvesting mechanisation in Croatian state forestry. Croatian journal of forest engineering 28(1): 63–82.

Bojanin, S., Krpan, A. P. B., 1994: Eksploatacija šuma pri različitim radnim uvjetima u Hrvatskoj. Šumarski list 118 (9/10): 271–282.

Bojanin, S., Krpan, A. P. B., 1997: Mogućnost tzv. visokoga i potpunog mehaniziranja sječe i izrade te mehaniziranja privlačenja drva u šumama Hrvatske (Possibilities for high level and complete mechanization in felling operations and mechanization in skidding in Croatian forests). Šumarski list 121(7–8): 371–381.

Brunberg, T., 1999: Battre lastutnyttjande hos skotare (Optimizing forwarder payloads). Skogforsk, Resultat 1:1–4.

Brunberg, T., 2001: Hydroflex – nytt koncept för att utnyttja skotarnas lastkapacitet bättre (Hydroflex: a new system for maximizing forwarder payloads). Skogforsk, Resultat 13: 1–4.

Brunberg, T., 2004: Underlag till produktionsnormer för skotare (Productivity-norm data for forwarders). Skogforsk, Redogörelse 3: 1–12.

Flisberg, P., Forsberg, M., Rönnqvist, M., 2007: Optimization based planning tools for routing of forwarders at harvest areas. Canadian journal of forest research 37(11): 2153–2163.

Freitag, B., Warkotsch, W., 2011: The use of swap bodies for skidding and roundwood transportation. In: Ackerman, P., Ham, H., Gleasure, E. (eds.), Fourth Forest Engineering Conference: Innovation in Forest Engineering – adapting to structural change, April 5–7, 2011 in White River, South Africa. Department of Forest and Wood Science (Stellenbosch University) in conjunction with IUFRO and FESA (Forest Engineering Southern Africa), pp. 130–130.

Ghaffarian, M. R., Stampfer, K., Sessions, J., 2006: Forwarding productivity in Southern Austria. Croatian journal of forest engineering 28(2): 169–175.

Horvat, D., Šušnjar, M., 2001: Neke značajke poljoprivrednih traktora prilagođenih šumskim radovima (Some characteristics of farming tractors used in forest work). In: Matić, S., Krpan, A. P. B., Gračan, J. (eds), Znanost u potrajnom gospodarenju hrvatskim šumama, Forestry Facultry Zagreb and Forestry Institute Jastrebarsko, Zagreb, Croatia, pp. 535–544.

Horvat, D., Zečić, Ž., Šušnjar, M., 2007: Morfološke i proizvodne značajke traktora Ecotrac 120V (Morphological characteristics and productivity of skidder ECOTRAC 120 V). Nova mehanizacija šumarstva 28 (Special Issue 1): 81–92.

ISO, 2009: Machinery for forestry – Mobile and self-propelled machinery – Terms, definitions and classification (ISO 6814:2009). Machinery. 1–7.

Jiroušek, R., Klvač, R., Skoupý, A., 2007: Productivity and costs of the mechanised cut-to-length wood harvesting system in clear–felling operations. Journal of forest science 53(10): 476–482.

Krpan, A. P. B., 1996: Problem privlačenja drva u nizinskim šumama Hrvatske (Problem of skidding timber in Croatian lowland forests). Šumarski list 120(3/4): 151–156.

Kühmaier, M., Stampfer, K., 2010: Development of a Multi-Attribute Spatial Decision Support System in Selecting Timber Harvesting Systems. Croatian journal of forest engineering 31(2): 75–88.

Kuitto, P. J., Keskinen, S., Lindroos, J., Oijala, T., Rajamäki, J., Räsänen, T., Terävä, J., 1994: Puutavaran koneellinen hakkuu ja metsäkuljetus (Mechanized cutting and forest haulage, In Finnish, English summary). Metsäteho Report 410, pp. 1–38.

Li, Y., Wang, J., Miller, G., McNeel, J., 2006: Production economics of harvesting small-diameter hardwood stands in central Appalachia. Forest products journal 56(3): 81–86.

Lindroos, O., Wasterlund, I., 2011: Larger loads and decreased damage – the potential of a new forwarding concept. In: Ackerman, P., Ham, H., Gleasure, E. (eds.), Fourth Forest Engineering Conference: Innovation in Forest Engineering – adapting to structural change, April 5–7, 2011 in White River, South Africa. Department of Forest and Wood Science (Stellenbosch University) in conjunction with IUFRO and FESA (Forest Engineering Southern Africa), pp. 166–166.

Löffler, H., 1989: Forstliche Verfahrenstechnik für Studierende der Forstwissenschaft (Manuscript). Universität München, pp. 1–516.

Lugmayr, J., Bauer, R., Gatterbauer, E., Hauer, H., Kindermann, G., Preier, P., Schnabel, G., Schönauer, H., 2009: »Forstmaschinen-CD, 4. Auflage«. Bundesforschungs und Ausbildungszentrum für Wald Naturgefahren und Landschaft (BFW), Institut für Waldwachstum und Betriebswirtschaft, Wien, Austria, CD-ROM.

Mederski, P. S., 2006: A comparison of harvesting productivity and costs in thinning operations with and without midfield. Forest ecology and management 224(3): 286–296.

Mihelič, M., Krč, J., 2008: Analysis of Inclusion of Wood Forwarding into a Skidding Model. Croatian journal of forest engineering 30(2): 113–125.

Minette, L. J., Moreira, F. M. T., de Souza, A. P., Machado, C. C., Silva, K. R., 2004: Análise técnica e econômica do forwarder em três subsistemas de colheita de florestas de eucalipto (Technical and economic analysis of a forwarder under three eucalyptus forest harvest subsystems). Revista Árvore 28(1): 91–97.

Nurminen, T., Korpunen, H., Uusitalo, J., 2006: Time consumption analysis of the mechanized cut–to–length harvesting system. Silva Fennica. 40(2): 335–363.

Pandur, Z., Vusić, D., Papa, I., 2009: Dodatna oprema za povećanje proizvodnosti forvardera. Nova mehanizacija šumarstva 30: 19–25.

Pentek, T., Pičman, D., Nevečerel, H., Lepoglavec, K., Papa, I., Potočnik, I., 2011: Primarno otvaranje šuma različitih reljefnih područja Republike Hrvatske (Primary Forest Opening of Different Relief Areas in the Republic of Croatia). Croatian journal of forest engineering 32(1): 401–416.

Pentek, T., Poršinsky, T., Šušnjar, M., Stankić, I., Nevečerel, H., Šporčić, M., 2008: Environmentally Sound Harvesting Technologies in Commercial Forests in the Area of Northern Velebit – Functional Terrain Classification. Periodicum biologorum 110(2): 127–135.

Poršinsky, T., 1997: Određivanje položaja Kockumsa 850 i Timberjacka 1210 u obiteliji forvardera morfološkom raščlambom (The morphological analysis determination of the Kockums 850 and Timberjack 1210 positions in the forwarder family). Mehanizacija šumarstva 22(3): 129–138.

Poršinsky, T., 2000: Čimbenici učinkovitosti forvardera Timberjack 1210 pri izvoženju oblog drva glavnog prihoda nizinskih šuma Hrvatske (Efficiency factors of Timberjack 1210 at forwarding the main felling roundwood in Croatian lowland forests). Forestry Faculty, University of Zagreb, MSc Thesis, pp. 1–140.

Poršinsky, T., 2002: Productivity factors of Timberjack 1210 at forwarding the main felling roundwood in Croatian lowland forests. Glasnik za šumske pokuse 39: 103–132.

Poršinsky, T., 2005: Djelotvornost i ekološka pogodnost forvardera Timberjack 1710 pri izvoženju oblovine iz nizinskih šuma Hrvatske (Efficiency and environmental evaluation of Timberjack 1710B forwarder on roundwood extraction from Croatian lowland forests). PhD Thesis, Forestry Faculty, University of Zagreb, pp. 1–170.

Poršinsky, T., Stankić, I., Bosner, A., Pentek, T., 2008: Morphological analysis of chainsaws. In: III International scientific conference FORTEHENVI, 26–30 May 2008. Prague, Czech Republic, POSTER.

Raymond, K. A., 1989: Mechanised shortwood thinning with forwarder extraction (Project Report 42). New Zealand Logging Industry Research Association, pp. 1–17.

Sabo, A., Poršinsky, T., 2005: Skidding of fir roundwood by Timberjack 240C from selective forests of Gorski Kotar. Croatian journal of forest engineering 26(1): 13–27.

Samset, I., 1990: Some observations on time and performance studies in forestry. Meddelelser fra Norsk Institutt for Skogforskning. 43(5): 1–80.

Samset, I., 1992: Forest operations as a scientific discipline. Meddelelser fra Skogforsk. 44(12): 1–48.

Sever, S., 1980: Istraživanje nekih eksploatacijskih parametara traktora kad privlačenja drva. Forestry Faculty, University of Zagreb, PhD Thesis, pp. 1–301.

Sever, S., 1988: Proizvodnost i perfomanse forvardera u radovima privlačenja drva. Mehanizacija šumarstva 18(5–6): 59–87.

Slabak, M., 1983: Forvarderi u svijetu i kod nas. Mehanizacija šumarstva u teoriji i praksi. Opatija, pp. 351–362.

Stankić, I., 2010: Višekriterijsko planiranje izvoženja drva forvarderima iz nizinskih šuma Hrvatske (Multicriterial planning of timber forwarding in Croatian lowland forests). Forestry Faculty, University of Zagreb, PhD Thesis, pp. 1–123.

Suvinen, A., 2006: Economic comparison of the use of tyres, wheel chains and bogie tracks for timber extraction. Croatian journal of forest engineering 27(2): 81–102.

Šušnjar, M., 1998: Istraživanje ovisnosti nekih tehničkih značajki iverača morfološkom raščlambom (Research of some chipper´s technical features by morphological analysis). Mehanizacija šumarstva 23(3–4): 139–150.

Šušnjar, M., Borić, D., 2008: Morfološka raščlamba farmerskih vitala (Morphological analysis of farmi winches). Nova mehanizacija šumarstva 29: 29–35.

Šušnjar, M., Horvat, D., Grahovac, I., 2007: Morfološka raščlamba šumskih hidrauličnih dizalica (Morphological analysis of forest hidraulic cranes). Nova mehanizacija šumarstva 28: 15–26.

Tiernan, D., Zeleke, G., Owende, P. M. O., Kanali, C. L., Lyons, J., Ward, S. M., 2004: Effect of working conditions on forwarder productivity in cut-to-length timber harvesting on sensitive forest sites in Ireland. Biosystems engineering 87(2): 167–177.

Tomić, I., 2007: Kako racionalizirati korištenje mehanizacije. Hrvatske šume, no. 123: 11–12.

Tufts, R. A., 1997: Productivity and cost of the Ponsse 15–series, cut–to–length harvesting system in southern pine plantations. Forest products journal 47(10): 39–46.

Tufts, R. A; Brinker, R. W., 1993: Productivity of a Scandinavian system while second thinning pine plantations. Forest products journal 43(11/12): 24–32.

Väätäinen, K., Asikainen, A., Sikanen, L., 2006: The cost effect of forest machine relocations on logging costs in Finland. Forestry Studies, Metsanduslikud Uurimused 45, pp. 135–141.

Väkevä, J., Kariniemi, A., Lindroos, O., Poikela, A., Rajamäki, J., Uusi-Pantti, K., 2001: Puutavaran metsäkuljetuksen ajanmenekki (Time consumption of timber haulage). Metsätehon raportti 123, pp. 1–41.

Wästerlund, I., Andersson, E., Bygdén, G., 2011: Fuel consumption driving with a forwarder on soft ground. In: Ackerman, P., Ham, H., Gleasure, E. (eds.), Fourth Forest Engineering Conference: Innovation in Forest Engineering – adapting to structural change, April 5–7, 2011 in White River, South Africa. Department of Forest and Wood Science (Stellenbosch University) in conjunction with IUFRO and FESA (Forest Engineering Southern Africa), pp. 174–174.

White, T., 2004: Factors Affecting Harvester and Forwarder Production. In: Making Cut-to-Length Logging Pay, FERIC. Kamploos, BC, Canada, pp. 1–30.

Zimbalatti, G., Proto, A. R., 2010: Productivity if forwarders in South Italy. In: FORMEC 2010, Forest Engineering: Meeting the Needs of the Society and the Environment, pp. 1–7.

Sažetak

Modeli proizvodnosti pri operativnom planiranju izvoženja drva forvarderima u Hrvatskoj

U području hrvatskih nizinskih šuma za skupljanje i privlačenje drvnih sortimenata primjenjuje se poseban oblik primarnoga transporta drva, za koji je znakovita potpuna odignutost tereta (oblovine) od tla, pri čemu se koriste forvarderi. Forvarderi su samopogonjena vozila namijenjena pomicanju stabala ili njegovih dijelova koji drvo izvoze utovareno u tovarnom prostoru vozila iz šumskoga bespuća do pomoćnoga stovarišta, odnosno šumske ceste. U sklopu istraživačkoga projekta »Usustavljenje normi i normativa«, koji financiraju Hrvatske šume d.o.o., razvijene su nove proizvodne norme izvoženja drva forvarderima.

Proizvodnost izvoženja drva ovisi o korištenom tipu vozila. Stoga je za provedbu istraživanja bilo potrebno prikupiti podatke o tehničkim značajkama novijih forvardera u Republici Hrvatskoj, ali i u svijetu. Potom se pristupilo morfološkoj raščlambi na osnovi koje su se vozila razvrstala u razrede, jer je neodrživo projektirati normu za svaki tip vozila zasebno. Klasterskom analizom dobivena su tri razreda forvardera. To su laki, srednje teški i teški forvarderi. Kao najvažniji čimbenik pri razvrstavanju pokazala se nosivost forvardera. Laki su nosivosti do 11 t, srednje teški od 11 do 14, a teški forvarderi imaju nosivost veću od 14 t. U hrvatskom šumarstvu koriste se uglavnom srednje teški i teški forvarderi, dok se umjesto lakih forvardera koriste razne inačice traktorskih ekipaža.

Primjena izvoženja drva razumijeva sortimentnu metodu izradbe oblovine. Stoga su značajke tovara (prosječan obujam komada i njegove dimenzije) posredno uvjetovane i prosječnim dimenzijama doznačenih stabala za sječu i izradbu. Spojeni su podaci iz dviju aplikacija (HsPPI i HsPRO) za ona radilišta na kojima se od početka primjene tih aplikacija izvozilo forvarderima. Na osnovi podataka o doznaci stabala oblikovane su značajke oblovine u etatu najzastupljenijih vrsta drva.

Informatička služba poduzeća Hrvatske šume d.o.o. preuzela je zadatak izrade sustava za prikupljanje i pohranu snimljenih podataka. Za pohranu se koristila baza podataka MS SQL Server 2000. Kao korisničko sučelje za prihvat podataka služila je web-aplikacija zasnovana na dinamičnim mrežnim stranicama koje se u potpunosti izvršavaju na poslužiteljskom računalu i izravno komuniciraju s bazom podataka. Sustav je izrađen pomoću tehnologije Microsoft ASP.NET, programiran u Visual Basic.NET-u, a izvršava se na poslužitelju Windows Server 2003.

Rad je forvardera istražen na 22 radilišta metodama studija rada i vremena, primjenom povratne metode kronometrije. Radi što korektnijega oblikovanja utrošaka vremena tim su podacima pridruženi i podaci prethodnih istraživanja, opsega 8 radilišta, te je oblikovanje utrošaka vremena rada zasnovano na podacima s ukupno 30 radilišta. Pri raščlambi su upotrijebljeni prikupljeni podaci o sastojinskim i terenskim utjecajnim čimbenicima izvoženja drva.

Pri planiranju privlačenja drva, kao najzahtjevnijoj sastavnici pridobivanja drva, postavljaju se zahtjevi za poznavanjem prisutnih utjecajnih čimbenika određenoga područja te njihova djelovanja na djelotvornost korištenih sredstava privlačenja drva. Važniji utjecajni čimbenici izvoženja drva iz sječina hrvatskih nizinskih šuma nastali iz ovoga istraživanja svakako su srednja udaljenost privlačenja, nosivost podloge (tla), obujam prosječnoga komada oblovine u tovaru, sječna gustoća te nosivost forvardera. Regresijskom raščlambom utvrđena je ovisnost trajanja pojedinih sastavnica rada o utjecajnim čimbenicima te je izrađen model proizvodnosti forvardera.

Po završetku istraživanja dobiveni je model prema zahtjevima naručitelja ugrađen u program HsPPi. Tu je aplikaciju razvila Informatička služba poduzeća Hrvatske šume d.o.o., a koristi se za planiranje proizvodnje. Glavni su dijelovi sustava za pripremu proizvodnje: priprema doznake, plan sječa, plan proizvodnje i plan prodaje.

Unutar dijela za izradu plana proizvodnje nalazi se i modul za izračun normativa izvoženja drva forvarderima. Ovdje razvijen i opisan sustav za planiranje normativa izvoženja drva forvarderima uskoro započinje s operativnom primjenom u hrvatskom državnom šumarstvu.

Ključne riječi: forvarder, norme proizvodnosti, planiranje, nizinske šume, Hrvatska

Authors' addresses – *Adresa autorâ:*

Igor Stankić, PhD
e-mail: igor.stankic@sumfak.hr
Assoc. Prof. Tomislav Poršinsky, PhD
e-mail: porsinsky@sumfak.hr
Department of forest engineering
Forestry Faculty, University of Zagreb
Svetošimunska 25, HR-10000 Zagreb
CROATIA

Željko Tomašić, PhD
e-mail: zeljko.tomasic@hrsume.hr
Ivica Tonković, dipl. ing.
e-mail: ivica.tonkovic@hrsume.hr
Marko Frntić, dipl. ing.
e-mail: marko.frntic@hrsume.hr
Hrvatske šume d.o.o. (Croatian forests LLC)
Directorate
Vukotinovićeva 2, HR-10000 Zagreb
CROATIA

Received (*Primljeno*): September 25, 2011
Accepted (*Prihvaćeno*): May 22, 2012