Morphological characteristics and productivity of skidder ECOTRAC 120V

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Abstract – Nacrtak

This paper presents the results of morphological analysis of the Croatian skidder ECOTRAC 120V, as well as the research of its productivity features in timber skidding from hilly terrain after preparatory felling and from mountainous terrain after selective felling. Morphological analysis was used for determining the dependence of morphological features of the skidder ECOTRAC 120V, as well as for establishing its belonging to the skidder's family. The characteristics of the researched skidder are small width relative to length, due to the requirements of its manoeuvrability in timber skidding on skid roads of up to 2.5 m in width, and higher engine power relative to skidder mass. Such considerations give justification for morphological analyses, because they provide the possibility of observing development trends of machines, as well as ways of finding the right design solutions for meeting the requirements for their use.

The comparison of two working sites in the research of productivity of skidders clearly shows that productivity primarily depends on harvesting density (working time at the felling site) and skidding speed, and that in this case a considerable difference in the size of the load is not a key factor of productivity in timber skidding.

Keywords: skidder ECOTRAC 120V, morphological analysis, timber skidding, daily output, unit cost

1. Introduction – *Uvod*

In hilly and mountain forests of Croatia, wheeled skidders equipped with winch are the most commonly used vehicles for timber skidding after preparatory and selective felling. Similarity between preparatory and selective fellings in hilly and mountain forests lies in approximately the same size of trees, so that the same methods and similar techniques may be applied in skidding the processed timber assortments. Based on the analysis of the annual allowable cut of the Croatian forestry by type of felling and terrain conditions, Krpan et al. (2003) determined the quantity of 1.4 mil. m^3 of timber assortments skidded by large skidders after preparatory and selective fellings in hilly and mountain forests.

Nowadays in Croatia, approximately 300 skidders owned by the company »Hrvatske šume« d.o.o. Zagreb, and about 100 skidders (rough estimate) owned by private contractors are in use. More than 100 of them are thinning skidders, with a mass lower than 4 t, which have been designed and manufactured in Croatia. The remaining 300 skidders of a mass of more than 7 t have been imported and they are used for skidding timber of larger size after final felling.

Based on the requirements of the Croatian forestry for such technology of timber skidding, and taking into consideration the current number of such skidders as well as the production possibilities of the factory »Hittner« d.o.o., the idea arose to develop a domestic skidder of a mass of more than 7 tons. Within the development project of the Ministry of Science, Education and Sports, the project of design and manufacture of the new skidder includes the manufacturer as well as forestry experts and scientists working at the Faculty of Forestry, whose task is to establish the basic technical and technological requirements for the skidder's construction using their knowledge and experience. The basic idea is that the newly produced skidder should fully meet the requirements for timber skidding in the Croatian forests.

The objective of this paper is to establish belonging of the new skidder to the skidder's family by

Fig. 1 Skidder ECOTRAC 120V
Slika 1. *Skider ECOTRAC 120V*

morphological analysis of the basic dimensions and to determine its productivity by work and time study at two characteristic working sites in timber skidding after preparatory and selective felling.

2. Skidder ECOTRAC 120V – *Skider ECOTRAC 120V*

The basic dimensions and mass distribution of the skidder ECOTRAC 120V are shown in Figure 2 (Horvat and Šušnjar 2005). The skidder mass together with the driver is 7257 kg (59% at the front axle and 41% at the rear axle). The maximum allowable mass at the skidder's rear axle is 6000 kg.

The skidder has a diesel engine, of a nominal power of 84 kW. It is equipped with a double-drum winch of the nominal tractive force of 80 kN. The pulling cable is 14 mm in diameter, and 70 m long per each drum. The winch is driven hydraulically, and steering is electro-hydraulic. The rear blade is used for receiving, protecting and anchoring purposes and it can be raised and lowered by two hydraulic cylinders.

3. Research methods – *Metode istraživanja*

Morphological analysis is used for establishing the current state, characteristics and patterns of forest machines as well as their possible development trends. On the basis of the selected geometric, mass and other values, dependences are expressed and judgement is made of the suitableness of the machine choice. The results of the analyses are used by forestry experts in selecting new machines, in establishing the most favourable use of machines under different work conditions and in determining parameters required for constructing new machines.

Bekker (1956) carried out one of the first morphological analyses of off-road vehicles by expressing his opinion that an object moving in a medium will acquire the form that will offer the lowest possible resistance to such movement. Therefore, the mor-

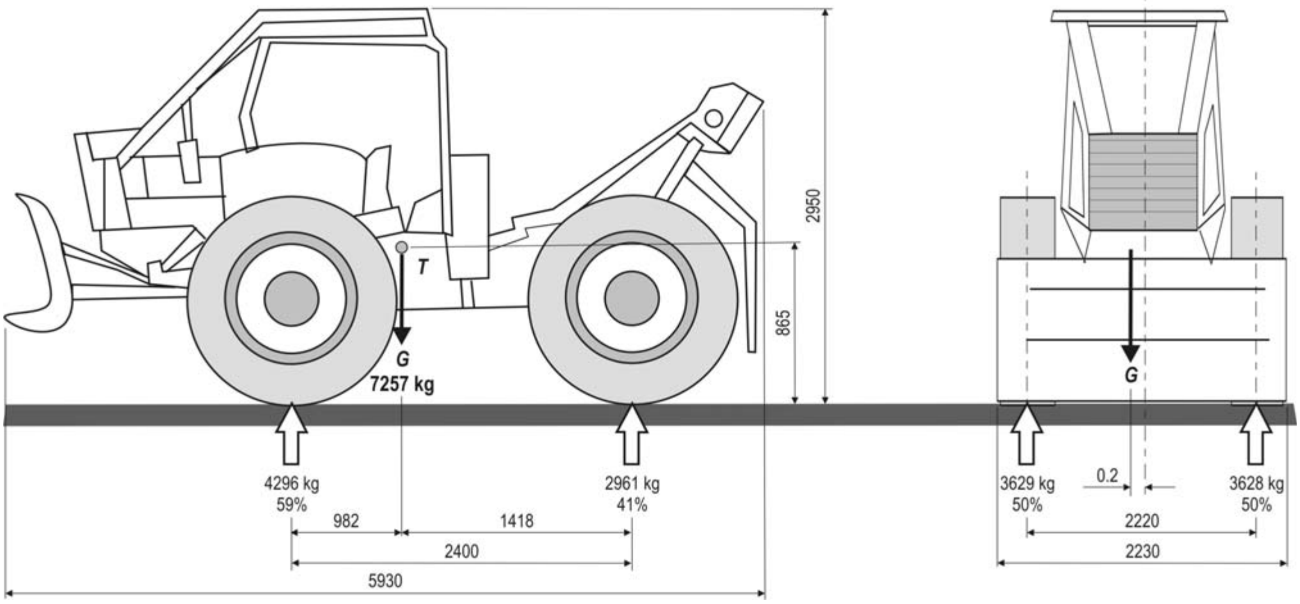

Fig. 2 Dimensions and mass distribution of the skidder ECOTRAC 120V
Slika 2. *Dimenzije i raspored mase skidera ECOTRAC 120V*

phological analysis may also be used for assessing the future development and not only for expressing the achieved levels of dimensional development of a vehicle or for trying to estimate the position of a specific vehicle in a group of similar ones.

By using morphological analysis, Sever (1980) compared forest skidders equipped with winch with adapted farm tractors, establishing undoubtedly that skidders could be classified in a separate group/family of vehicles with specific morphological characteristics. In performing the project task related to medium skidder, Sever and Horvat (1985) used the results of morphological analysis. The same authors (1992B) analysed the basic morphological characteristics of different forest vehicles. They expressed their opinion that such data could be used by designers in designing vehicles and by forestry experts in making their choice.

The whole idea of this analysis is based on correlation dependence between individual pairs of morphological characteristics of skidders and on comparison of the position of ECOTRAC 120V within the whole family (group) of skidders. Known databases were used for the purpose of morphological analysis (Sever and Horvat 1992A, Sever and Horvat 1992B, Sever and Horvat 1997, Horvat et al. 2002), and they were later up-dated with data obtained from databases of characteristics of forest machines compiled by the Department of Forest Engineering at the Institute of Forestry under the Austrian Ministry of Agriculture and Forestry (FBVA 2003). The database contains a total of 91 types of skidders.

Table 1. Working site characteristics
Tablica 1. *Značajke radilišta*

Forest Office *Šumarija*	Đurđevac	Senj
Type of felling *Vrsta sječe*	Preparatory felling *Pripremni sijek*	Selective felling *Preborni sijek*
Terrain *Teren*	Hilly – *Brdovit*	Mountain – *Planinski*
Above sea level, m *Nadmorska visina*, m	185–245	960–1155
Skid road slope *Nagib vlaka*	+4%	–9.6%
Soil condition *Stanje tla*	Humid – *Vlažno*	Humid – *Vlažno*
Tree species *Vrsta drva*	Oak – *Hrast* (4,3%) Beech – *Bukva* (35.1%) Other – *OTL* (60.6%)	Beech – *Bukva* (84.3%) Fir – *Jela* (15.7%)
Average tree volume, m^3 *Prosječni obujam stabla*, m^3	0.52	1.59
Harvesting density, m^3/ha *Sječna gustoća*, m^3/ha	128.11	46.05
Method of timber processing *Metoda izradbe drva*	Cut to length *Sortimentna*	Half-tree *Poludeblovna*
Average skidding distance, m *Srednja udaljenost privlačenja*, m	257	335

Nine morphological characteristics of skidders were selected from the database, out of which five were the basic characteristics (length *L*, width *B*, height to cabin roof H_C, mass *m*, engine power *P*) and three were calculated characteristics (form indexes H_C/L and *W/L*, unit mass g_m). If the vehicle is presented in the form of a prism, then the ratios *H/L* (height/length) and *B/L* (width/length) express significant volume characteristics and they are called form indexes. Form indexes are the most important characteristics for the vehicles belonging to the same family, and they are used for describing them and as initial information on the researched vehicle and its classification into an already known family of vehicles.

The data are presented in tables in a computer database, so that they can be easily accessible for determining possible dependences. Correlation dependences between certain morphological characteristics of skidder were determined with the use of the software programme REG.EXE (Hitrec and Horvat 1987). In the presentations of dependences between morphological characteristics, skidders are divided into two basic categories with respect to mass: medium skidders (mass up to 5000 kg) and skidders of a mass exceeding 5000 kg. The said division of skidders based on mass was laid out by Horvat and Sever (1995), and Horvat (1996).

In timber skidding by the skidder ECOTRAC 120V at two working sites, time consumptions of work operations were measured by snap-back chronometry method, and work and time study of the skidder were carried out. Standard measuring equipment was used. Supporting measuring and description information were collected by adequate methods. Mathematical/statistical processing of data was carried out by standard PC packages, and processing of data by software programme *Statistica 7*.

4. Research working sites – *Istraživana radilišta*

The research of productivity was carried out at two working sites: in the area of the Forest Office of Đurđevac, forest management unit »Đurđevačka Bilogora«, compartment 64a, and in the area of the

Forest Office of Senj, forest management unit »Senjsko bilo«, compartment 24a. The phases of felling/processing of trees and timber skidding at the working sites are separated in time. The data presented in Table 1 show the diversity of stand, relief and technological characteristics of the working sites. Preparatory felling was carried out at the working site of the Forest Office of Đurđevac, while selective felling was carried out at the working site of Senj in a stand with a predominant share of beech trees. In skidding timber, skidders travelled on skid roads.

5. Research results – *Rezultati istraživanja*

5.1 Morphological analysis – *Morfološka raščlamba*

By use of morphological analysis, dependences were determined between individual morphological characteristics of the skidder ECOTRAC 120V, and its family was established as well as its position within the whole family (group) of skidders.

Figure 3 shows the relationship between form indexes of the skidder family. It can be seen that most values of form indexes are under the line $H = B$, i.e. they are in the area where height prevails over width of the vehicle. It is generally characteristic of tractors used for skidding/forwarding timber (adapted farm tractors, skidders with winch, forwarders) to have form indexes located in the area under the line $H = B$. This characteristic is the result of the requirement for extremely good manoeuvrability during work in forest stands. Vehicles of smaller width enable easier access to processed timber assortments and cause lower disturbance of forest soil and less damage to standing trees. The group of medium skidders is shifting right in the direction of higher vehicles relative to their length.

The relationship between form indexes of the skidder ECOTRAC 120V is located at the very edge of the skidder field and its characteristic is a suitably small width of the vehicle relative to its length. The reason of its position is based on the requirements of the forestry profession in designing this skidder. Skid roads in hilly and mountainous regions of Croatia are intended for tractors for timber skidding of an overall width of up to 2.5 m (Pičman and Pentek 2003), and hence in designing the skidder, attention was focused on meeting the requirements of the forestry profession so as to fit the dimensions of the skidder into given widths of the built skid roads. Total width of the skidder is 2230 mm, and together with its total length of 5930 mm, it results in a low form index *B/L* (width/length) of 0.38.

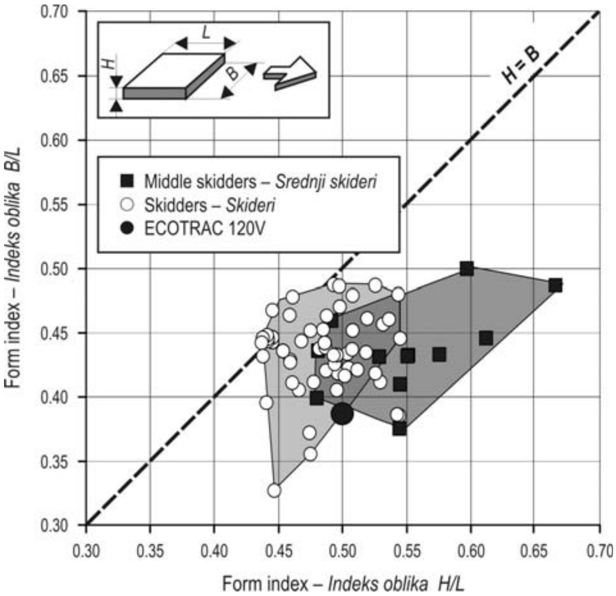

Fig. 3 Form index
Slika 3. *Indeksi oblika*

The skidder mass is considered a significant morphological characteristic. Although higher mass is considered unfavourable as a rule, with skidders and other vehicles designed for skidding timber, mass has a broader meaning in terms of exploitation, because in timber skidding together with a part of mass of the skidded load it makes the effect of adhesive load and thus enables a wheel-to-soil transfer of thrust force (Sever and Horvat 1985). On the other hand, however, higher mass of skidders is considered unfavourable due to higher rolling resistance and higher wheel pressure to soil, which causes damage to forest soil.

Comparison between skidder dimensions and mass is shown in Figures 4, 5 and 6. In determining the dependence, exponential regression equations were chosen due to the fact that dimensions have a limit value (asymptotic value) determined either by legal regulations or by technological requirements. Very strong regression and correlation coefficients have been determined for the established dependences of the skidder length, width and height relative to mass.

It can be seen in Figures 4 and 5 that the length increases faster than width with the increase of mass. This phenomena is explained by the said limitation of the skidder's width imposed by the width of skid roads and requirements for vehicles as narrow as possible for the work in forest in order to reduce the threat of causing damage to standing trees. The increase of the skidder length with the increase of mass is unfavourable in terms of its manoeuvrability in

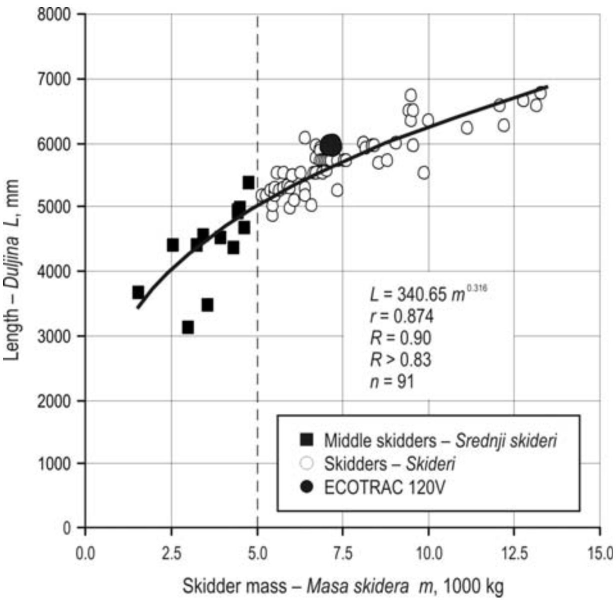

Fig. 4 Dependence of length on skidder mass
Slika 4. *Ovisnost duljine o masi skidera*

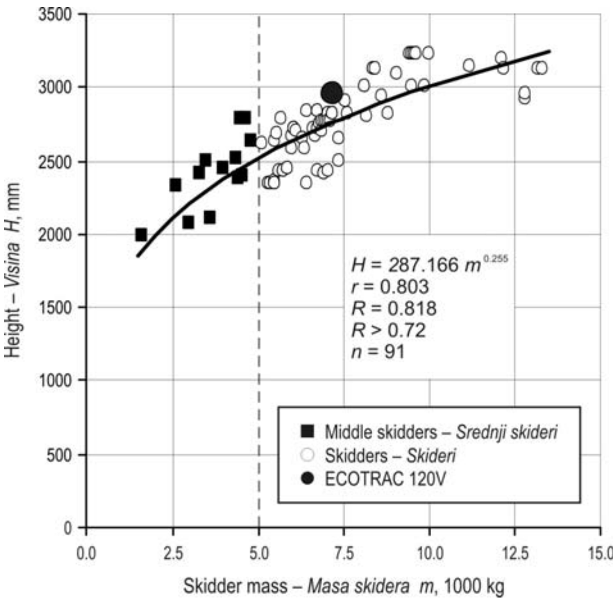

Fig. 6 Dependence of height on skidder mass
Slika 6. *Ovisnost visine o masi skidera*

forest stands, because higher length implies a larger turning radius of the skidder and consequently its lower mobility. However, the unfavourable trend of increase of the skidder length with the increase of mass may be moderated to a certain extent by articulated steering, where by a centrally installed articulated joint a lower turning radius may be provided despite a relatively high distance between axles or total length.

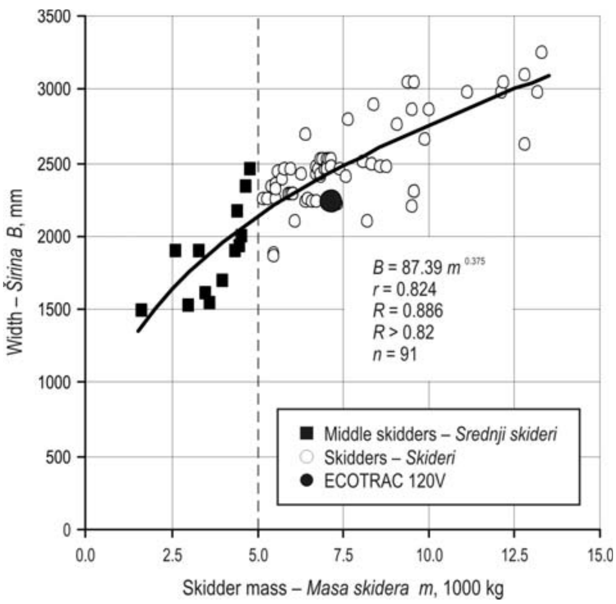

Fig. 5 Dependence of width on skidder mass
Slika 5. *Ovisnost širine o masi skidera*

The presented dependence shows that the researched skidder is located near the equalisation curves of the observed dependence of the skidder dimensions on mass, and hence it can be concluded that if fully belongs to the family and group of skidders. Width is under the equalisation curves, and the reason of its lower width is explained by compliance with the requirements of the forestry profession and design solutions. The skidder's length and height are located under the equalisation curves. Larger length is caused by the construction of the front blade operated by two long-stroke hydraulic cylinders, which makes it largely movable, as well as by the construction of the rear anchoring blade. Total height is higher than the average, as it is defined as the distance from the ground to the highest point of the skidder, and with this skidder this point is the peak edge of the exhaust pipe elevated above the cabin roof so as to comply with the requirements of ISO standards for preventing the possibility of entrance of exhaust gases into the cabin.

The analysis of the dependence of the driving engine power on mass is significant from the standpoint of the division of skidders as a separate family of vehicles with respect to adapted farm tractors. The ratio between the engine power and mass of the vehicle may be interpreted as the ratio of the engine power that can be carried by a vehicle mass unit. Sever (1980) came to the conclusion that the skidder mass unit was much lower than the mass unit of adapted farm tractors. The author explained the said phenomenon by the skidder construction with a

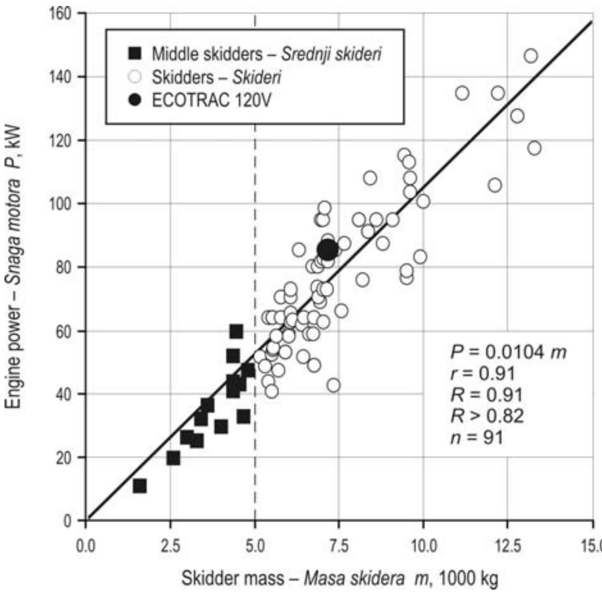

Fig. 7 Dependence of engine power on skidder mass
Slika 7. *Ovisnost snage motora o masi skidera*

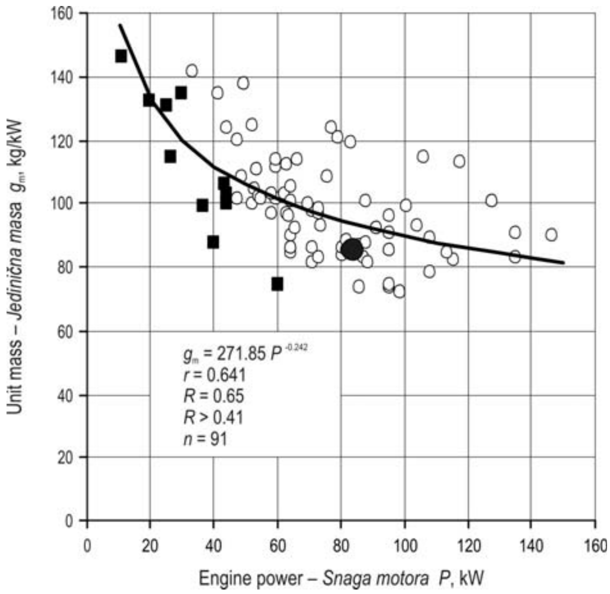

Fig. 8 Dependence of unit mass on engine power
Slika 8. *Ovisnost jedinične mass o snazi motora skidera*

higher safety coefficient due to more demanding work conditions in timber skidding. Similarly, work speeds of farm tractors engaged in agricultural production are higher than speeds at which timber are skidded by skidders.

By the presentation of the said dependence only for the skidder family, a very strong linear dependence was established of the engine power on mass (Fig. 7). With the increase of the skidder mass, the power of the driving engine increases linearly, and consequently it can be concluded that 100 kg of skidder mass »carries« approximately 1 kW of the driving engine power.

The researched skidder ECOTRAC 120V is located above the equalisation line due to the driving engine power of 84 kW, which along with the mass of 7257 kg means that a skidder mass of 100 kg carries 1.16 kW of the driving engine power, i.e. the skidder has a unit power of 11.6 kW/t and a unit mass of 86.4 kg/kW. The increased engine power is the result of the requirement of forestry experts based on the experience of many years of use of skidders in timber skidding from selective mountain stands.

Further analysis of the dependence between the driving engine power and skidder mass was carried out based on an indicator known as the tractor unit mass (g_m) defined as the ratio between net tractor mass (m) and driving engine power (P). With the dependence of unit mass on skidder engine power (Fig. 8), a strong non-linear correlation was established. As expected, due to the increase of the engine power, the researched skidder had lower unit mass than the one characteristic of the group. The skidder unit masses range between 70 kg/kW and 150 kg/kW. This result of the analysis indicates the increasing trend of skidders unit masses with respect to those recorded in previous researches. Sever (1980) outlined unit masses for skidders ranging between 60 kg/kW and 85 kg/kW. This trend of installing engines of lower power in skidders can be explained as the development of a new quality typical of a specific family and their distinctive divergence from the usual rules of construction of farm tractors, from which skidders were originally developed.

5.2 Loads – *Tovari*

Data on loads are shown in Table 2. The average volume of the load in preparatory felling is almost half the size of an average load characteristic of selective felling (2.78 m^3 versus 5.34 m^3), but it averagely consists of a higher number (8 versus 5.7) smaller (0.35 m^3 versus 0.93 m^3) and shorter pieces (3.9 m versus 7 m).

As the diameters of the skidded logs are of similar size at both felling sites, higher volume of the average load was recorded at the working site with selective felling as the result of skidding a lower number of much longer assortments.

5.3 Time consumption – *Utrošak vremena*

On the basis of the conducted time study, the structure of total consumed time was determined, as

Table 2 Load characteristics by working sites
Tablica 2. *Značajke tovara po radilištima*

Type of felling – *Vrsta sječe*	Preparatory felling – *Pripremni sijek*	Selective felling – *Preborni sijek*
Total skidded timber, m^3 – *Ukupno privučeno drvo*, m^3	125.25	255.01
Total number of pieces – *Ukupan broj komada*	359	275
Total number of cycles – *Ukupan broj turnusa*	46	48
Load volume, m^3/cycle – *Obujam tovara*, m^3/tura	2.78 (0.78–4.52)*	5.34 (1.63–10.36)*
Number of pieces per load – *Broj komada u tovaru*	8 (3–17)*	5.7 (3–9)*
Piece length, m – *Dužina komada*, m	3.9 (2–7.8)*	7 (2–13.2)*
Piece volume, m^3 – *Obujam komada*, m^3	0.35 (0.06–2.13)*	0.93 (0.06–3.87)*
Piece diameter, cm – *Promjer komada*, cm	32(14–73)*	39 (13–75)*

* minimums and maximums – *najmanje i najveće opažanje*

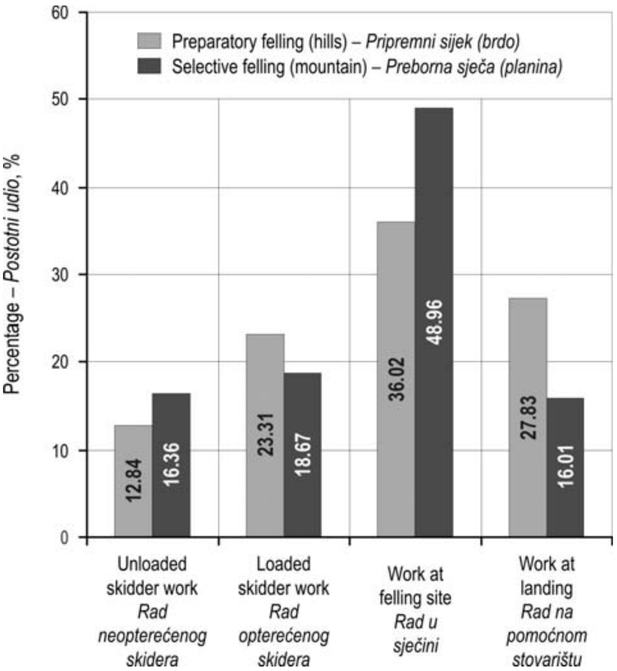

Fig. 9 Structure of effective time consumption
Slika 9. *Struktura utrošenoga efektivnoga vremena*

well as the structure of effective time and delay times. The work in skidding roundwood from a hilly working site after preparatory felling is characterised by an extremely low time efficiency (effective time is 47.06% of total time), unlike skidding from the mountain working site after selective felling (effective time is 80.2% of total time). Distribution as a component of effective time (Fig. 9) is relatively similar for both working sites. However, with selective felling a larger share of work time is spent at the felling site and a smaller at the roadside landing. Considering the fact that a smaller number of longer pieces was recorded in the load with selective felling, a smaller share of work time is expected at the roadside landing. Despite higher speed of cable pulling out and winching, a considerable share of work time at the felling site with selective felling is the result of a greater average winching distance (21.8 m) and considerable moving of the skidder during load forming, and a relatively short time spent at the roadside landing. In the preparatory felling, the average winching distance is 10.5 m. The share of unloaded and loaded skidder travel is similar for both working sites.

At the hilly working site, the unit effective time was 8.06 min/m^3 with the daily output of 20.88 m^3/day, and with selective felling the unit effective time was 9.88 min/m^3 with the daily output of 31.88 m^3/day. As the skidder worked longer (on the average 392.52 min/day) at the working site of Senj (selective felling) than at the working site of Đurđevac (preparatory felling), where the skidder worked on the average for 357.75 min/day with a much higher share of effective time, it is no wonder that the established daily output with the selective felling was higher by 11.00 m^3 or 34.5%.

5.4 Allowance time – *Dodatno vrijeme*

The structure of allowance time is shown in Figure 10. The meal time was calculated on the basis of a 30-minute break in an 8-hour working time.

Total allowance time of the skidder Ecotrac 120V at the hilly working site is 347.53 minutes (34.25% of effective time), and at the mountain working site it is 451.98 minutes, (17.95% of effective time). The factors of allowance time are 1.34 in the first case and 1.18 in the second.

5.5 Cycle time – *Vrijeme turnusa*

Figure 11 shows the structure of modelled cycle times for the felling site and skid road travel over a

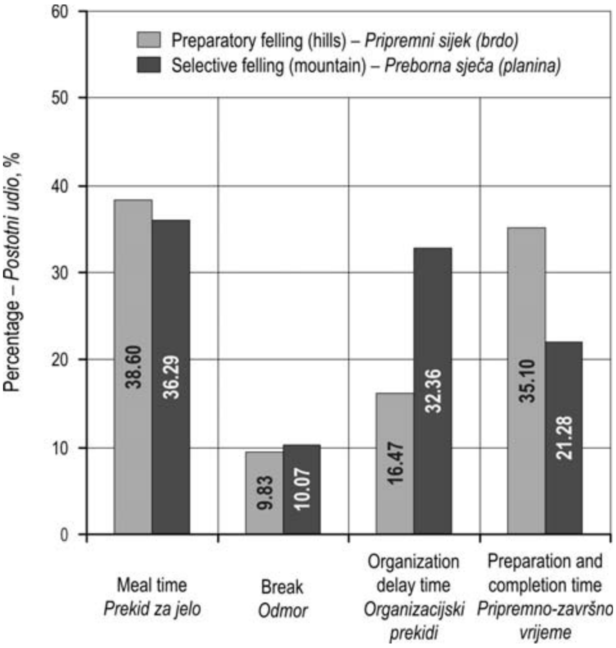

Fig. 10 Structure of allowance time
Slika 10. *Struktura dodatnoga vremena*

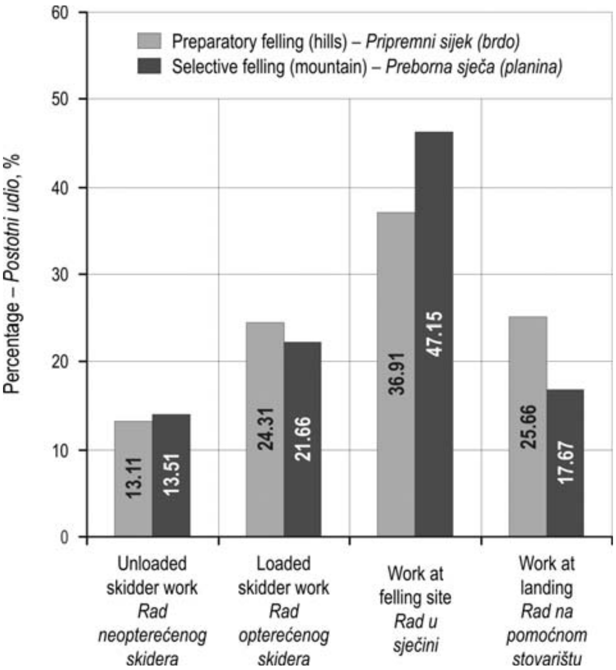

Fig. 11 Structure of modelled effective time
Slika 11. *Struktura oblikovanoga efektivnoga vremena*

distance of 300 m as well as for roadside landing travel of 50 m. The effective cycle time at the hilly working site during preparatory felling is 21.43 minutes, and at the mountain working site during selective felling 54.44 minutes, which is by 33.01 minutes more. Time standard at the hilly working site is 10.35 min/m^3, and at the mountain working site 12.03 min/m^3 (Table 3). During selective felling at the mountain working site, consumption of fixed times is high and namely 64.43% of effective cycle time (54.51% at the hilly working site), with larger shares of loading (47.15%). Thus 10.24% more time was consumed for loading at the hilly working site after preparatory felling. The share of time of unloading is smaller by 7.99% than that at the hilly working site.

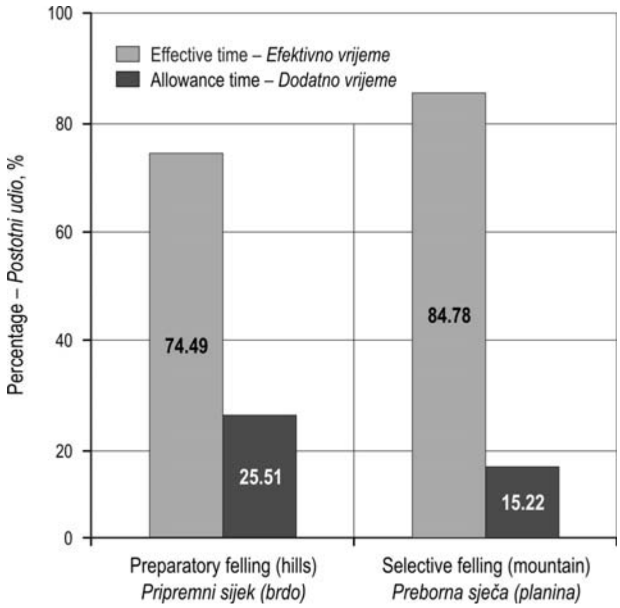

Fig. 12 Percentage of effective and allowance time
Slika 12. *Postotni udio efektivnoga i dodatnoga vremena*

Table 3 Modelled time standards and daily outputs of the skidder Ecotrac 120V
Tablica 3. *Oblikovana norma vremena i dnevni učinak skidera Ecotrac 120V*

Type of felling *Vrsta sječe*	Preparatory felling (hill) *Pripremni sijek (brdo)*	Selective felling (mountain) *Preborna sječa (planina)*
Average load volume, m^3 *Prosječni obujam tovara*, m^3	2.78	5.34
Standard time, min/m^3 *Norma vremena*, min/m^3	10.35	12.03
Daily output, m^3/day *Dnevni učinak*, m^3/dan	46.38	39.92

5.6 Skidder speeds, speeds of cable pulling out and winching – *Brzine traktora, brzine izvlačenja užeta i privitlavanja*

The speeds of loaded and unloaded skidders (loaded and unloaded travel) were calculated by use of times obtained by multiple linear regression analysis. At the hilly working site (Koprivnica), the unloaded skidder travels downhill on skid road, and the loaded skidder uphill at a slope of +4%. At the mountain working site (Senj) the situation is the other way round, the unloaded skidder travels uphill and the loaded skidder downhill at a slope of –9.6%. Table 4 shows the coefficients of equalisation equations of travel times with correlation factors.

In calculating the travel time of the loaded skidder in the hilly region, the following relevant parameters were used: distance (l), soil condition (s_t), road slope (α), average daily temperature (T) and load volume (q).

$$v = a + b_1\, l + b_2\, s_t + b_3\, \alpha + b_4\, T + b_5\, q, \text{ (min)}$$

The same parameters were used with the unloaded skidder except load volume.

$$v = a + b_1\, l + b_2\, s_t + b_3\, \alpha + b_4\, T, \text{ (min)}$$

In observing the travel of loaded skidders at roadside landing, the following parameters were taken into consideration: distance (l), load volume (q) and number of pieces in a load (n).

$$v = a + b_1\, l + b_2\, q + b_3\, n, \text{ (min)}$$

With unloaded skidders, only the travel distance (l) was observed.

$$v = a + b_1\, l, \text{ (min)}$$

Table 4 Equation parameters of multiple linear regression analysis
Tablica 4. *Parametri jednadžbi multiple linearne regresijske analize*

Type of time Vrsta vremena	Parameters – *Parametri*						
	a	b_1	b_2	b_3	b_4	b_5	*R*
Preparatory felling (hill) – *Pripremni sijek (brdo)*							
1. Felling site and skid road *Sječina i traktorski put*		l	s_t	α	T	q	
Unloaded skidder travel *Vožnja neopterećenoga skidera*	–0.6773	0.0077	0.3589	–0.0120	0.0354		0.95
Loaded skidder travel *Vožnja opterećenoga skidera*	–4.3734	0.0185	0.7128	0.3274	–0.0443	0.1077	0.93
2. Roadside landing *Pomoćno stovarište*		l	q	n			
Unloaded skidder travel *Vožnja neopterećenoga skidera*	0.1630	0.0083					0.61
Loaded skidder travel *Vožnja opterećenoga skidera*	0.2291	0.0105	–0.0016	0.0110			0.60
Selective felling (mountain) – *Preborna sječa (planina)*							
1. Felling site and skid road *Sječina i traktorski put*		l	s_t	α	q		
Unloaded skidder travel *Vožnja neopterećenoga skidera*	–0.9118	0.0174	0.7894	0.1620			0.95
Loaded skidder travel *Vožnja opterećenoga skidera*	0.5990	0.0229	–0.5145	0.1172	0.3077		0.96
2. Roadside landing *Pomoćno stovarište*		l	q	n			
Unloaded skidder travel *Vožnja neopterećenoga skidera*	0.1289	0.0126					0.61
Loaded skidder travel *Vožnja opterećenoga skidera*	0.3588	0.0005	–0.0732	0.2233			0.12

The average travel speeds of unloaded skidders over a distance ranging between 50 m and 500 m are 5.69 km/h at the hilly working site, and 2.20 km/h at the mountain working site (Fig. 13). Loaded skidders travel at an average speed of 3.55 km/h (hilly working site) and 1.67 km/h (mountain working site). Despite downhill travel of the loaded skidder (–9.6%), the speed of skidding in the mountainous terrain is much lower than the speed in the hilly region, as the result of the driver's decision, who could not drive such a large load at a higher speed (5.34 m^3). As expected, the unloaded skidder travelled faster in the hilly region than the unloaded skidder downhill in the mountainous terrain.

On the basis of equations, skidder speeds were calculated for different distances, and they are shown in Figure 14 together with other constant parameters. Due to downhill travel of the loaded skidder in the selective felling of the mountainous region, the speeds of unloaded and loaded travel are similar, and in the hilly region the loaded skidder travels uphill at a much lower speed that the unloaded skidder. Generally, it can be concluded that in a hilly region travel speeds are higher due to smaller load.

By comparison between skidder speeds at the working sites and those obtained by calculation and measurement presented in Table 5 (Horvat and Šušnjar 2005), it can be concluded that the driver used »the 1st fast gear« in driving the unloaded skidder at the mountain working site, and »the 2nd fast gear« at the hilly working site. In downhill timber skidding at the mountain working site of Senj »the 1st slow gear« was used, and in uphill timber skidding at the hilly working site of Đurđevac »the 2nd slow gear« was used. On the basis of the used transmission gears and obtained travel speeds of unloaded and loaded skidders, assessment may be made of how good the transmission ratios are of the power transmission system, and the most loaded transmission gear pairs in timber skidding performed by skidders may be established.

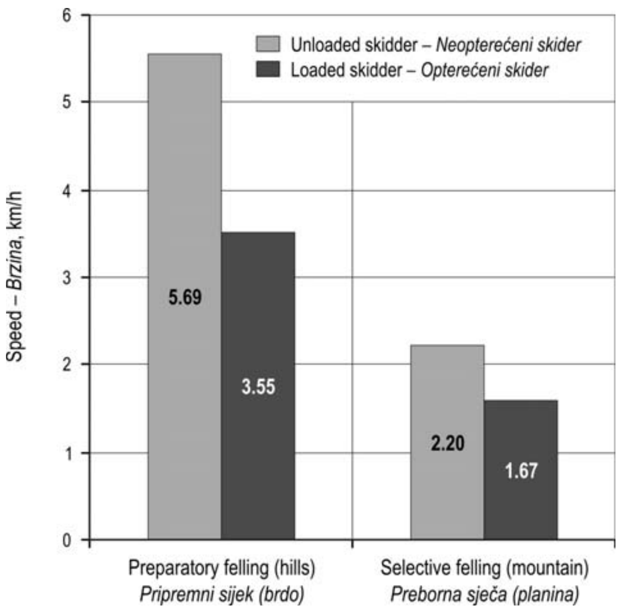

Fig. 13 Average speeds
Slika 13. *Prosječne brzine kretanja*

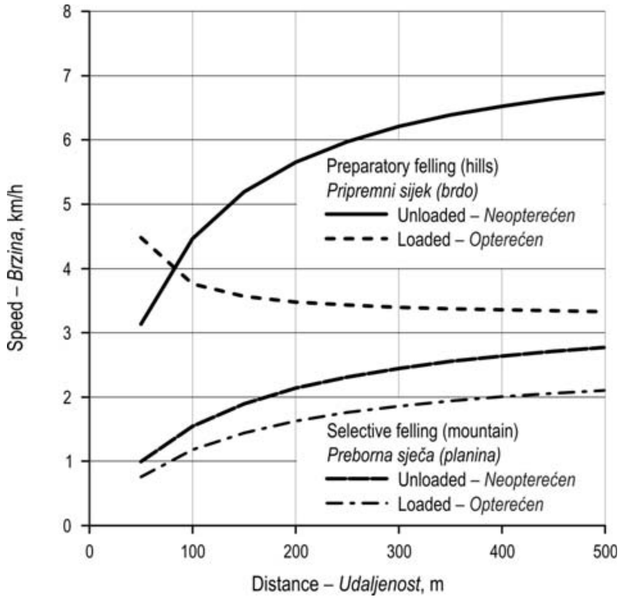

Fig. 14 Skidder speeds on skid road and felling site
Slika 14. *Brzine vožnji skidera po vlaci i sječini*

The average speed of pulling out the cable at hilly working sites was 1.10 km/h at an average distance of 10.5 m, and pulling of the cable was faster at the mountain working site (1.66 km/h) at a higher average distance (21.8 m). Multiple regression analysis showed that the time of pulling the cable at the mountain working site is significantly affected by terrain distance and slope, and in the preparatory felling by distance and air temperature.

Winching of timber was slower (0.99 km/h) in hilly areas after preparatory felling than in mountain stands after selective felling (1.8 km/h). Multiple regression analysis showed that the time of load winching at the mountain working site is significantly affected by terrain distance and accessibility, and in the preparatory felling only by distance.

It is known that the speeds of pulling and winching depend on terrain and stand factors, technical characteristics of the winch and cable, as well as on the distance of pulling the cable and size of individual loads. Based on technical data on winch Hittner 2 x 80, Horvat and Šušnjar (2005) calculated the

Table 5 Measured and calculated speeds of the skidder ECOTRAC 120V
Tablica 5. *Mjerene i proračunate brzine kretanja skidera ECOTRAC 120V*

Transmission gear (Forward) *Stupanj prijenosa (naprijed)*	Speed, km/h – *Brzina*, km/h	
	measured *mjerena*	calculated *proračunata*
1 Slow gear – *1. Spori hod*	3.01	2.9
2 Slow gear – *2. Spori hod*	5.17	5.3
3 Slow gear – *3. Spori hod*	8.65	8.7
4 Slow gear – *4. Spori hod*	13.58	14.1
5 Slow gear – *5. Spori hod*	20.72	21.1
1 Fast gear – *1. Brzi hod*	4.02	4.1
2 Fast gear – *2. Brzi hod*	7.25	7.4
3 Fast gear – *3. Brzi hod*	11.88	12.3
4 Fast gear – *4. Brzi hod*	19.36	19.8
5 Fast gear – *5. Brzi hod*	28.87	29.7

nominal winching speeds of 1.26 m/s (4.32 km/h) with empty drum, and 2.24 m/s (8.06 km/h) with full drum. It can be clearly seen that lower winching speeds were attained than the calculated nominal speeds. The reason lies in the fact that during winching the engine ran at lower revolution rates, causing lower oil flow in the winch drive hydraulic system and this resulted in lower winching speed. Nominal winching speeds can be attained at the nominal engine rotation speed. Taking into account the known dependence of pressure in the hydraulic system on the second power of the pump rotation speed, it can be concluded that the winch attained still sufficient tractive forces at lower engine speed. Considering the working possibilities of the winch and winching requirements at the working sites of Đurđevac and Senj, it can be concluded that the winch can be successfully used under severe conditions (higher terrain slope, larger loads) when higher winching resistances are encountered.

5.7 Standard times, daily outputs and skidding costs – *Norme vremena, dnevni učinci i troškovi privlačenja*

Standard times, daily outputs and skidding costs were calculated in dependence on skidding distances for both working sites.

The unloaded skidder consumes 1.34 to 4.46 minutes per cycle at a distance ranging between 100 m and 500 m at the hilly working site of Đurđevac, and between 3.88 and 10.83 minutes per cycle at the same distance at the mountain working site of Senj. The loaded skidder usually needs more time at the same skidding distances. So, at the hilly working site a loaded skidder requires 1.60 to 9.01 minutes per cycle, and in the mountain 5.09 to 14.26 minutes. Travel times of unloaded and loaded skidders at the landing are only shown for the distance of 100 m, which corresponds approximately to the average skidder travel distance at most working sites. Consequently the unloaded skidder consumed 1.00 minute for a distance of 100 m at the landing at the hilly working site of Đurđevac, and 1.39 minutes at the working site of Senj. At the landing, the loaded skidder consumes 1.37 minutes and 2.07 minutes, respectively. For other operations at the landing at the hilly working site of Đurđevac, the skidder consumes 4.07 minutes and 6.90 minutes at the mountain working site of Senj.

The skidder working time at a felling site involves all working operations (positioning, pulling the cable, bunching, winching), which take place at individual working sites, and it is considered as the average time consumed for a cycle, i.e. fixed time. So the skidder consumed 4.07 minute by cycle at the hilly working site of Đurđevac, and 25.69 minute at the mountain working of Senj, which is 3.3 times more. This can be explained by more time required for positioning (moving) and bunching (terrain accessibility and workers' skill), by double longer distance of pulling and winching, as well as by terrain configuration, or work methods (harvesting density).

Total travel time of the skidder cycle at the hilly working site of Đurđevac ranges between 23.21 and 37.34 minutes, and at the mountain working site of Senj between 53.10 and 72.12 minutes.

Standard time at the hilly working site of Đurđevac ranges between 8.35 min/m^3 and 13.43 min/m^3, and at the mountain working site of Senj between 9.94 min/m^3 and 13.51 min/m^3.

According to the calculated values, the daily output from 57.49 m^3/day and 35.74 m^3/day (100–500 m) can be achieved at the hilly working site. At the mountain working site, the daily output from 48.53 m^3/day to 35.54 m^3/day can be achieved for the same distance (Table 6).

Costs per product unit increase with the increase of skidding distance. The daily calculation of direct costs of the researched skidder amount to EUR 214.92 according to the official calculations of costs of »Hrvatske šume« d.o.o. Zagreb for the year 2007.

In the preparatory felling at a skidding distance from 100 m to 500 m at the hilly working site of Đurđevac, the costs range between 3.74 EUR/m^3 and 6.01 EUR/m^3. At the mountain working site of Senj at a distance from 100 m to 500 m, the costs range between 4.45 EUR/m^3 and 6.05 EUR/m^3. For

Table 6 Calculated travel times, standard times and daily outputs of skidder
Tablica 6. *Izračunata vremena vožnje, norma vremena i dnevni učinci skidera*

Skidding distance, m *Udaljenost privlačenja, m*	Skidder travel – *Vožnja traktora* Felling site *Sječina* Unloaded skidder, min *Neopterećeni skider, min*	Loaded skidder, min *Opterećeni skider, min*	Roadside landing *Pomoćno stovarište* Unloaded skidder, min *Neopterećeni skider*	Loaded skidder, min *Opterećeni skider, min*	Feling site work, min *Rad u sječini, min*	Work on landing, min *Rad na pomoćnom stovarištu, min*	Effective time, min *Efektivno vrijeme, min*	Allowance time, min *Dodatno vrijeme, min*	Total time per cycle, min *Ukupno vrijeme turnusa, min*	Standard time, min/m^3 *Norma vremena, min/m^3*	Daily output, m^3/dan *Dnevni učinak, m^3/day*
Preparatory felling (hill) – *Pripremni sijek (brdo)*											
100 + 100	1.34	1.60	1.00	1.37	7.91	4.07	17.29	5.92	23.21	8.35	57.49
200 + 100	2.12	3.45	1.00	1.37	7.91	4.07	19.92	6.82	26.74	9.62	49.90
300 + 100	2.90	5.30	1.00	1.37	7.91	4.07	22.55	7.72	30.28	10.89	44.08
400 + 100	3.68	7.15	1.00	1.37	7.91	4.07	25.18	8.62	33.81	12.16	39.47
500 + 100	4.46	9.01	1.00	1.37	7.91	4.07	27.81	9.53	37.34	13.43	35.74
Selective felling (mountain) – *Preborna sječa (planina)*											
100 + 100	3.88	5.09	1.39	2.07	25.69	6.90	45.02	8.08	53.10	9.94	48.27
200 + 100	5.62	7.38	1.39	2.07	25.69	6.90	49.05	8.80	57.86	10.83	44.30
300 + 100	7.36	9.67	1.39	2.07	25.69	6.90	53.08	9.53	62.61	11.72	40.94
400 + 100	9.09	11.97	1.39	2.07	25.69	6.90	57.11	10.25	67.36	12.61	38.05
500 + 100	10.83	14.26	1.39	2.07	25.69	6.90	61.14	10.98	72.12	13.51	35.54

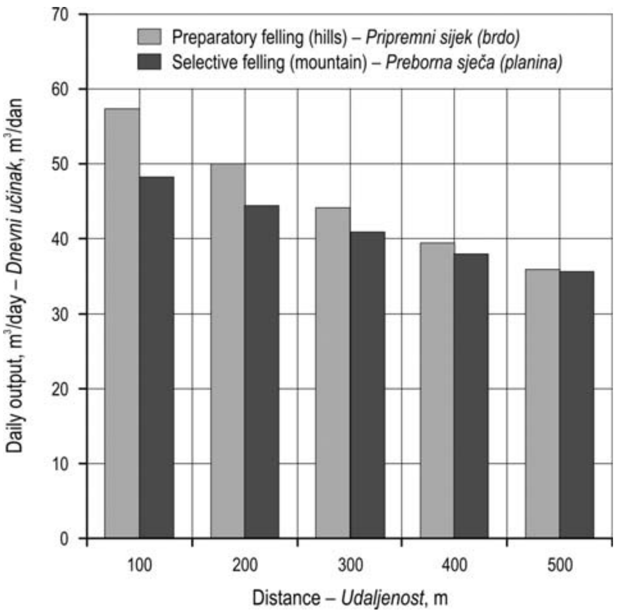

Fig. 15 Daily outputs depending on skidding distance
Slika 15. Dnevni učinci u ovisnosti o udaljenosti privlačenja

the skidding distance of 300 m + 100 m, the costs amount to 4.88 EUR/m^3 for the hilly working site. For the mountain working site the same costs amount to 5.25 EUR/m^3, which is by 0.37 EUR/m^3, or 7.1% more than the costs for the hilly working site of Koprivnica.

6. Conclusions – *Zaključci*

Morphological analysis was used for determining dependences between individual morphological characteristics of the skidder ECOTRAC 120V and for establishing that it belongs to the skidder family. The researched skidder has small width relative to length due to the requirements of its manoeuvrability in timber skidding on skid roads of up to 2.5 m in width. The unfavourable increase of the skidder length caused by the construction of the front and rear blade has no adverse effect on the skidder manoeuvrability due to a centrally installed articulated joint.

The increase of the skidder unit mass has been observed in the whole skidder family. The achievable value of the tractive force at the wheels also depends on technical characteristics of the driving engine and transmission system, as well as on the skidder mass, which makes the effect of adhesive weight and the required soil traction. The increase of the engine power relative to skidder mass enabled higher travelling speed of the skidder and provided the wheel thrust force required for overcoming the tractive and rolling resistance, by which work efficiency would also be increased and particularly so on sloped terrain.

Such considerations give justification for morphological analyses, because they provide the possibility of observing development trends of engines, as well as ways of finding the right design solutions for meeting the requirements for their use.

Productivity expressed through standard times, daily outputs and costs are only slightly different at the hilly working site after preparatory felling and in the mountain with the selective forest management. The comparison of two working sites in the research of skidder productivity clearly shows that productivity primarily depends on harvesting density (working time at the felling site) and skidding speed, and that in this case a considerable difference in the size of the load is not a key factor of productivity in timber skidding.

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Sažetak

Morfološke i proizvodne značajke traktora Ecotrac 120V

U prigorskim i brdskim predjelima za privlačenje drva upotrebljavaju se u prvom redu kotačni skideri opremljeni šumskim vitlom. U prigorskim i brdskim šumama u Hrvatskoj za privlačenje se iz oplodnih i prebornih sječa drva koriste skideri s vitlom. Danas u Hrvatskoj trenutačno radi oko 300 skidera u vlasništvu poduzeća »Hrvatske šume« d.o.o. Zagreb te oko 100 skidera (procjena) u vlasništvu privatnih poduzetnika. Temeljem potreba hrvatskoga šumarstva za takvim načinima privlačenja drva, trenutačnoga broja skidera i mogućnosti proizvodnje tvornice »Hittner« d.o.o. nastala je ideja o razvoju domaćega skidera mase preko 7 tona. Osnovna je zamisao da novonastali skider bude u potpunosti pogodan zahtjevima izvođenja radova privlačenja drva u hrvatskim šumama. Cilj je rada morfološkom raščlambom utvrditi izvedivost i opravdanost zahtjevanih morfoloških i tehničkih značajki skidera te ustanoviti njegovu proizvodnost na dvama karakterističnim radilištima pri privlačenju drva iz oplodne i preborne sječe.

Osnovne su dimenzije i raspored masa skidera ECOTRAC 120V prikazane na slici 2. Za potrebe morfološke raščlambe korištena je baza podataka koja sadrži 91 tip skidera. Odabrano je devet osnovnih morfoloških značajki skidera: duljina (L), širina (B), visina do krova kabine (H_C), masa (m), snaga motora (P), indeksi oblika (H_C/L) i (W/L), jedinična masa (g_m). Utvrđene su korelacijske ovisnosti između određenih morfoloških značajki skidera.

Ispitivani se skider odlikuje malom širinom vozila s obzirom na duljinu zbog potrebe njegova kretanja pri privlačenju drva na izgrađenim trakorskim putovima ukupne širine do 2,5 m, te većom snagom motora u odnosu na masu skidera. Nepovoljan rast duljine skidera s povećanjem mase ne utječe na kretnost skidera zbog središnje postavljenoga zgloba. Povećanjem snage motora u odnosu na masu skidera omogućeno je povećanje brzine kretanja skidera uz ostvarivanje potrebne obodne sile na kotačima za svladavanje otpora vuče i otpora kotrljanja, čime bi se ujedno povećala učinkovitost rada. Ova razmatranja pokazuju da su morfološke raščlambe opravdane jer se mogu uočiti smjerovi razvoja strojeva te načini pronalaženja konstrukcijskih rješenja za zadovoljavanje zahtjeva njihove uporabe.

Istraživanje proizvodnosti provedeno je na dvama radilištima: na brdskom radilištu Đurđevac obavljen je pripremni sijek, a na planinskom radilištu Senj preborni sijek u sastojini s pretežitim udjelom bukve. Pri privlačenju drva skiderom ECOTRAC 120V na oba radilišta povratnom metodom kronometrije mjereni su utrošci vremena radnih operacija i zahvata te proveden studij rada i vremena skidera. Odgovarajućim su metodama prikupljeni pomoćni mjerni i opisni podaci. Matematičko-statistička je obrada podataka provedena u računalnom programu Statistica 7.

Na osnovi provedenoga studija vremena određena je struktura ukupno utrošenoga vremena, efektivnoga vremena i općih vremena. Na slici 11 prikazana je struktura oblikovanih vremena turnusa za vožnju po sječini i vlaci na udaljenost od 300 m te za vožnju po pomoćnom stovarištu od 50 m. Brzine su punih i praznih traktora izračunate pomoću vremena koja su izračunata multiplom linearnom regresijskom analizom. Pri izračunu vremena vožnje opterećenoga traktora uzeti su sljedeći utjecajni parametri: udaljenost (l), stanje tla (s_t), nagib puta (α), prosječna dnevna temperatura (T) i obujam tovara (q). Kod neopterećenoga traktora uzeti su isti parametri osim obujma tovara. Kod opterećenih traktora po pomoćnom stovarištu promatrana je udaljenost (l), obujam tovara (q) i broj komada u tovaru (n), a kod neopterećenih samo udaljenost vožnje. Prosječne brzine kretanja neopterećenih traktora iznose 5,69 km/h na brdskom radilištu, odnosno 2,20 km/h na planinskom radilištu (slika 13). Opterećeni se traktori kreću prosječnom brzinom od 3,55 km/h (brdsko radilište) i 1,67 km/h (planinsko radilište). Na temelju jednadžbi izračunate su za različite udaljenosti brzine skidera i prikazane na slici 14. Zbog kretanja opterećenoga skidera niz nagib na planinskom, prebornom radilištu brzine su prazne i pune vožnje slične, a u brdu se opterećeni skider kreće uzbrdo mnogo sporije od neopterećenoga. Općenito, u brdu su brzine vožnje veće zbog manjega tovara.

Temeljem raščlambe izmjerenih i proračunatih brzina kretanja skidera ECOTRAC 120V može se zaključiti da je vozač skidera koristio stupanj prijenosa »1. brzi hod« pri kretanju neopterećenoga traktora na planinskom radilištu, odnosno »2. brzi hod« na brdskom radilištu. Pri privlačenju drva skiderom niz nagib na planinskom radilištu Senj korišten je stupanj prijenosa »1. spori hod«, a pri privlačenju drva uz nagib na brdskom radilištu Đurđevac stupanj prijenosa »2. spori hod«. S obzirom na korištene stupnjeve prijenosa i ostvarene brzine kretanja neopterećenoga i opterećenoga skidera može se donijeti sud o dobroj izvedenosti prijenosnih odnosa sustava *prijenosa snage, ali isto tako o najopterećenijim stupnjevima prijenosa pri radu skidera na privlačenju drva.*

Multipla regresijska analiza pokazala je da na vrijeme izvlačenja užeta na planinskom radilištu signifikantno djeluju udaljenost i nagib terena, a u pripremnom sijeku udaljenost i temperatura zraka. Na vrijeme privitlavanja tovara na planinskom radilištu signifikantno djeluju udaljenost i prohodnost, a u pripremnom sijeku samo udaljenost.

Prosječne su brzine izvlačenja užeta manje od proračunatih nazivnih brzina. Razlog leži u tome da je pri radu vitla korišten manji broj okretaja motora i time manji protok ulja u hidrauličnom sustavu za pogon vitla, što je rezultiralo manjom brzinom privitlavanja. Nazivne se brzine privitlavanja mogu ostvariti uz najveći broj okretaja motora odnosno najveći protok ulja u hidrauličnom sustavu. S obzirom na radne mogućnosti vitla i zahtjeve privitlavanja na radilištima može se zaključiti da se vitlom može raditi i pri težim uvjetima (veći nagibi terena, veći tovari) kada se pojavljuju veći otpori privitlavanja.

Prozvodnost iskazana normom vremena, dnevnim učinkom i troškom u ovisnosti o udaljenosti privlačenja neznatno se razlikuje na radilištima. Usporedbom dvaju radilišta pri istraživanju proizvodnosti skidera vidljivo je da značajna razlika u veličini tovara nije ključni čimbenik pri privlačenju drva.

Ključne riječi: skider ECOTRAC 120V, morfološka raščlamba, privlačenje drva, dnevni učinak, troškovi

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