Morphological Analysis of Forest Tractor Assemblies

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Abstract – Nacrtak

The results of this paper present the morphological analysis of nine different types of tractor assemblies used in forestry practice in timber forwarding from thinning operations of lowland forests. Among these tractor assemblies 4 types are older, equipped mechanical cranes. The remaining 5 tractor assemblies, manufactured more recently, are equipped with hydraulic cranes, and two of them are additionally equipped with double-drum winches.

According to the research results, older tractor assemblies have very favourable morphological characteristics, according to which they are classified as ecologically acceptable vehicles for the timber forwarding from thinning operations in lowland forests. However, work technology requires from the vehicle to reach each timber assortment processed in the stand, which also means higher possibility of damage to forest soil of poor bearing strength in lowland areas.

Technical design of more recent types of tractor assemblies ensures environmental suitability in timber forwarding from thinning operations. The installation of an articulated joint on the semi-trailer shaft ensures small turning diameter and hence lower risk of causing damage to standing trees. The adequate breadth of tractor assemblies is achieved by use of narrower tyres on rear tractor wheels. Installation of the forest winch on the tractor assembly causes lower soil tracking and lower damage to soil and standing trees. They also exert imaginary pressure on the soil between 2 kPa and 4 kPa and hence they are more adequate for the work on forest soils of poor bearing strength than forwarders, as the lowest imaginary pressure exerted by forwarders is around 4 kPa.

Keywords: *tractor assembly, morphological analysis, timber forwarding, ecological suitability, thinnings*

1. Introduction – *Uvod*

Timber harvesting from thinning operations in lowland forests of the east part of Croatia is very significant due to considerable quantities of wood – around 50% of the total annual allowable cut, ecological sensitivity and economic efficiency.

Naturally regenerated forests in the east part of Croatia are considered the most valuable forests in the country, but also ecologically the most sensitive. These forests developed on deep pseudoglay type of soils characterised by poor load-carrying capacity and high water content. These forests are operated and maintained on the principle of sustainable management, and hence problems arise in carrying out wood production operations. Due to the above mentioned characteristics of forest soil, timber is mostly forwarded so as to minimise the damages to soil. During winter, the extraction of timber from the main felling is carried out by forwarders. However, forwarders are not suitable for extracting timber from thinning operations during vegetation periods. Due to their large mass (also including load mass), they exert large contact pressure on the soil, which is of poor bearing strength in that period, so that serious damage is caused.

Based on the experience of forestry experts, and along with a generally accepted standpoint on the need of timber forwarding from lowland forests since the beginning of the mechanisation of timber extraction operations, tractor assemblies have been used in thinning operations of the said forests. Tractor assembly means an adapted farming tractor with forest semi-trailer and installed crane. The advantage of tractor assemblies in timber forwarding from thinning operations of lowland forests lies in the vehicle mass and lower contact pressure on forest soil, which results in lower damage to forest soil and the remaining standing trees and young trees. The tractor assembly is also less costing than forwarder, which affects the reduction of cost per product unit.

The application of forest machines in thinning operations in Croatia started in early 70s of the last century. After the use of the first assembly in 1968, the production and use of the domestic tractor assembly started in 1972. The first tractor assembly of that kind was the so-called Pionir (Fig. 1) which was equipped with mechanical crane and mechanically driven winch. In mid eighties the number of tractor assemblies Pionir reached its maximum of 70 pieces. After 25 years this assembly is still in use, primarily because of its extremely simple design and consequently also a relatively low purchase price, as well as low operating and maintenance costs (Beuk et al. 2007).

Ecological issues demanded winching of processed assortments (logs) from the stand (felling site) to one of the parallel strip roads (laid out at a 75 m distance between them). Due to technical deficiencies of the Pionir assembly, it was difficult to carry out such operations, so that they used to enter into the stand until the stump, by which both ecological and economic features were disturbed. Further improvements were made by providing better forest opening with a 37.5 m distance between parallel strip roads. On the other hand these tractor assemblies are technically and technologically out-of-date and hence they cannot meet many modern criteria related to ergonomic and safety requirements (driver's cabin and seat, need for frequent rising to the loading area, etc.).

Since the 90s, different designs of tractor assemblies have been used. Mechanical cranes on the tractor assembly have been replaced with hydraulic cranes, which enabled lifting of heavy timber assortments and an ergonomically more favourable hydraulic steering, later replaced with electro-hydraulic steering.

Based on practice in using tractor assemblies Horvat et al. (2004A) have made the following recommendations related to the basic technical characteristics of the tractor assembly: semi-trailer loading capacity – 6 t, tractor power – approximately 60 kW, hydraulic crane of net lifting capacity – more than 40 kNm, the same tractor and semi-trailer track width – less than 1.7 m, total length of the assembly – up to 9 m, clearance – larger than 300 mm, double-drum winch with tractive force of more than 50 kN and reduction of the turning diameter with the use of the articulated joint shaft or movable bogie wheels.

The latest design of tractor assembly from 2004 is based on the above recommendations. The so-called new tractor assembly Formet consists of the following elements: farming tractor Steyr 8090 with narrow track, double-drum winch Igland 6002 Pronto TL, hydraulic crane Igland 43–65, semi-trailer Metalac S-6 with loading capacity of 6 t (Fig. 2). Nowadays farming tractors Belarus 920 and Belarus 952 are often used instead of the tractor Steyr 8090.

The most significant technical and exploitation characteristics of the new tractor assembly Formet lie in its independent hydraulic crane of good lifting capacity, bigger cabin with turning seat, double-drum winch with good tractive force, higher semi-trailer loading capacity as well as the tractor of a modern design in terms of better technical and safety features.

Additional equipping of tractor assemblies with forest winch enabled them to move exclusively on parallel trails, from which winching of timber assortments was carried out and then loading by crane,

Fig. 1 Tractor assembly Pionir
Slika 1. *Traktorski skup Pionir*

Fig. 2 Tractor assembly Formet
Slika 2. *Traktorski skup Formet*

without having to enter into the stand and approach each processed assortment at the distance of the crane reach. When the tractor assembly moves exclusively on forest roads and trails the possibility is reduced of causing damage to forest soil (soil compaction, formation of wheel rut) by passage of the loaded vehicle, especially in conditions of its poor bearing strength.

However, a considerable part of felled trees is not in the reach of the crane and then winching is required. Wästerlund (1994) emphasises that winching within a stand, where thinning operations are carried out, may cause extremely serious damage to the remaining trees in the stand. During winching, relatively high resistances can occur on the soil, depending on winching coefficients. Horvat et al. (2005) determined that the winching coefficient depends on the weight, form and position of logs in the felling site, and that higher resistances were recorded in skidding with the larger end turned forward. When winching logs, as opposed to for example timber skidding, where one end of the load is elevated on the rear part of the skidder, the log is dragged on the soil in full weight. During such operation higher resistances occur, and the negative effect is enhanced by ploughing effect of the front end of the log.

When the tractor assembly is engaged in thinning stands, lower ground tractive resistance of wood assortments from the felling site to the skid trail can be achieved by directional felling. In this way, the assortments would be directed with their thinner end toward the skid trail already in the phase of felling and the winching distance would also be reduced. Directional felling of trees has also some ecological advantages, because it causes less damage to forest soil, and economic advantages as higher productivity is achieved by the tractor assembly due to lower winching distances.

The chosen technology of timber forwarding from thinning operations in lowland fellings, which is represented in the use of tractor assemblies equipped with semi-trailer, double-drum winch and hydraulic forest crane, is acceptable from both the theoretic/scientific and professional point of view, and it is in accordance with the ecological requirements on soil and stand protection.

2. Research methods – *Metode istraživanja*

The aim of this paper is to carry out the morphological analysis of different types of forest tractor assemblies and, based on the obtained results, to indicate the specifics of their technical and technological characteristics with respect to forwarders, and ecological suitability of tractor assemblies for performing the operations of timber forwarding from thinnings in lowland forests.

Morphological analysis is used for determining the current state, features and patterns, as well as possible development trend of forestry machines. Based on the selected geometric, mass and other values, dependencies are expressed and assessment is made of the machine choice. The results of the performed analyses are used by forestry experts in choosing new machines, selection of the machine for the most favourable use in different work conditions, for defining framework parameters in designing new machines within known families (groups).

This method was introduced by Bekker in 1956 primarily with the aim of assessing the advantages of vehicles moving off road. He stated that the ratio of the vehicle geometric indicators, and especially the so-called factor of the vehicle load-bearing surface, determine the vehicles manoeuvrability on soft soils (Horvat et al. 2004B).

Horvat and Kristić (1999) outlay the first morphological analysis of thinning tractor assemblies (tractor with semi-trailer and hydraulic crane) as the starting point in seeking the optimum solution for lowland forests. Morphological analysis was carried out so that length, breadth, track width, height, clearance, loading capacity, maximum crane reach and maximum lifting moment were observed with respect to semi-trailer mass.

The research was carried out by measurement of the basic dimension and mass characteristics on 9 different types of tractor assemblies. The method of morphological analysis was used for the determination of dependences between the selected characteristics of tractor assemblies:

⇒ mass of tractor assembly, tractor, forest semi-trailer with hydraulic crane,

⇒ length, breadth and height of tractor assembly,

⇒ turning diameter of tractor assembly,

⇒ imaginary pressure on soil.

The measurement of mass of tractor, tractor semi-trailer and the whole tractor assembly was carried out with four scales of the Swedish manufacturer TELUB. All scales are connected to a measuring amplifier HBM Spider 8, which is directly connected to a laptop. The results of measurement were read from each scale by use of the software programme Catman 4.0.

In order to measure the mass accurately, all wheels of the tractor assembly have to be positioned horizontally. This is why the four scales were first placed under the tractor wheels, and the semi-trailer wheels on wooden supports of the scales' height. Then the scales were placed under the semi-trailer wheels,

Fig. 3 Measuring of tractor mass
Slika 3. *Mjerenje mase traktora*

Fig. 4 Measuring of semi-trailer mass
Slika 4. *Mjerenje mase poluprikolice*

and wooden supports under the tractor wheels. The sum of all readings represents the total mass of the unloaded tractor assembly. The sum of masses on the scales under the semi-trailer wheels represents the semi-trailer mass (Fig. 4).

The forest semi-trailer is connected to the tractor by a shaft and hence part of the semi-trailer weight is transferred to the rear wheels of the tractor. In order to measure accurately the weight of the tractor alone, it is necessary to lift the semi-trailer shaft with a manual hydraulic crane (Fig.3). During shaft lifting, the scales readings change up to the moment when the semi-trailer stops to exert load on the rear part of the tractor and only then the scales readings show a stable mass value, which is also the tractor mass.

The measurement tape was used for determining the dimensions of the tractor assembly in accordance with the following definitions:

⇒ length – horizontal distance from the vertical surface touching the most remote point of the front part of the vehicle (front part of the tractor) to the vertical surface touching the most remote point of the rear part of the vehicle (rear part of the semi-trailer).

⇒ breadth – horizontal distance between two vertical surfaces parallel with the longitudinal vehicle axis touching the most remote points on both sides of the axes (in measuring the maximum breadth of the tractor assembly it was the distance between outer edges of the semi-trailer wheels or outer edges of wheels of the rear tractor axis),

⇒ height – vertical distance between the horizontal soil surface and horizontal surface touching the highest point of the vehicle (the highest point of the hydraulic crane in transport position).

The measurement of the diameter of the turning circle was carried out in accordance with the standard ISO 789-3:1996 (Agricultural tractors – Test procedures – Part 3: Turning and clearance diameters). The standard defines the diameter of the turning circle as the diameter of the smallest circle made by the outer peripheral parts of unloaded vehicle in turning without braking.

The measurement of the smallest turning circle was made in turning of each tractor assembly to the left and right. Each tractor assembly started this turning drive on a plane surface until the smallest turning circle was achieved (Fig. 5). The smallest turning circle is achieved at the moment when due to turning, the shaft comes quite close to the tyre of the tractor rear wheel (Fig. 6). Some types of tractor assemblies (more recent ones) have an articulated

Fig. 5 Tractor assembly in achieving the smallest turning circle
Slika 5. *Traktorski skup pri postizanju najmanjega kruga okretanja*

Fig. 6 Contact between semi-trailer shaft and tractor rear wheel tyre in achieving the smallest turning circle

Slika 6. *Dodir ruda poluprikolice i gume stražnjega kotača traktora pri postizanju najmanjega kruga okretanja*

Fig. 7 Marking of the smallest turning circle
Slika 7. *Označivanje najmanjega kruga okretanja*

joint shaft so that before measuring the smallest turning circle, the articulated joint shaft was positioned at the highest deviation angle from the longitudinal axis of the tractor assembly.

During circling of the tractor assembly in achieving the smallest turning circle, several places that define the outer parts of the tractor assembly were marked on the ground and namely: tractor front wheels moving on the outer edge of the circle or the edge of the front tractor bumper (Fig. 7). Fig. 8 shows schematically the marked places on the turning circle of the tractor assembly as well as the marked measurement distances (A, B and C).

The diameter of the smallest turning circle was calculated by the following equation:

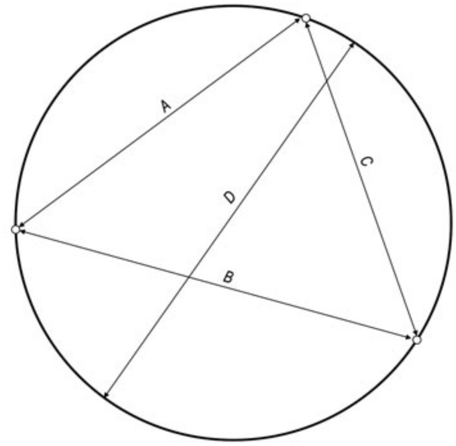

Fig. 8 Schematic presentation of the measured values
Slika 8. *Shema mjerenih vrijednosti*

$$D = \frac{2ABC}{\sqrt{2(A^2B^2 + A^2C^2 + B^2C^2) - (A^4 + B^4 + C^4)}}$$

In assessing the morphological features of the vehicles travelling off road, Bekker (1956) introduced the term imaginary pressure (p_{im}), defining it as the ratio between the vehicle weight (G) and surface of the imaginary rectangle (A_{im}) defined by the vehicle length (L) and breadth (B).

$$p_{im} = \frac{m \cdot g}{B \cdot L}$$

It can be clearly seen from this definition that this is a theoretic feature suitable for comparison of vehicles and that it has not a physical meaning. Based on the research of the actual pressure of the vehicle on the wheel's contact surface, the same author concluded that there is a strong correlation between this parameter and imaginary pressure.

The imaginary pressure was calculated based on the measured values of the total mass and the basic dimensions for each tractor assembly.

The regression analysis was used for the research of possible stochastic dependencies between satisfactorily correlated variables. The exponential regression software programme REG.EXE, primarily developed for the research of the wheel's slip curves (Hitrec and Horvat 1987), was used for the regression of dependencies of data pairs, which showed by the increase of the independent variable that the data of the dependent variable have an asymptotic trend of increase. The above said software programme shows the correlation strength of the selected re-

Table 1 Measured masses and basic dimensions of tractor assemblies
Tablica 1. *Izmjerena masa i osnovne dimenzije traktorskih skupova*

Tractor assembly *Traktorski skup*		Mass *Masa*			Dimension of tractor assembly *Dimenzije traktorskoga skupa*			Turning diameter *Promjer kruga okretanja*
		Tractor assembly *Traktorski skup*	Tractor *Traktor*	Semi-trailer *Poluprikolica*	Length *Duljina*	Breadth *Širina*	Height *Visina*	
		m	m_t	m_p	L	B	H	D
		kg	kg	kg	mm	mm	mm	m
1	Pionir Tigar 42	3573	2754	819	7890	1880	3685	11.8
2	Pionir IMT 541	3870	3059	811	8380	1820	3415	14.3
3	Pionir Tigar 49 DV	4136	3301	835	8230	1850	3450	12.8
4	Pionir IMT 549	4186	3328	858	8320	1800	3081	13.6
5	FMV Steyr 964	6478	4798	1680	9300	1940	2844	14.3
6	Formet Belarus 920	8758	6418	2340	10480	2060	2995	13.7
7	Formet Belarus 952	8774	6576	2198	10420	1930	2780	12.0
8	Vinkum Belarus 952	8811	6188	2623	10230	2130	3190	14.2
9	Vinkum Steyr 9094	8824	6469	2355	10310	2200	3790	12.5

gression models by use of three parameters: r – correlation coefficient, R – correlation index and $R >$ – testing of correlation index based on number of observations.

3. Research results – *Rezultati istraživanja*

In this paper tractor assembly is considered a special forest vehicle, although it is composed of a farming tractor as the driving means, forest semi-trailer, crane and forest winch if required.

The results of this paper show the morphological analysis of nine different types of tractor assemblies used in forestry practice in timber forwarding from thinning operations in lowland forests. Among these tractor assemblies 4 types were older, equipped mechanical cranes – tractor assemblies Pionir with different driving means – tractor. The remaining 5 tractor assemblies were equipped with hydraulic cranes, and two of them were additionally equipped with double-drum winches (tractor assemblies Formet).

The following tractor assemblies were researched along with the description of individual components:

⇒ 1. Pionir – tractor Tigar 42, semi-trailer Metal S-5 of loading capacity of 5t, mechanical crane,

⇒ 2. Pionir – tractor IMT 541, semi-trailer Metal S-5 of loading capacity of 5t, mechanical crane,

⇒ 3. Pionir – tractor Tigar 49 DV, semi-trailer Metal S-5 of loading capacity of 5t, mechanical crane,

⇒ 4. Pionir – tractor IMT 549, semi-trailer Metal S-5 of loading capacity of 5t, mechanical crane,

⇒ 5. FMV – tractor Steyr 964, semi-trailer Metalac S-5 of loading capacity of 5t, hydraulic crane FMV470 (reach – 6 m, gross lifting capacity – 47 kNm),

⇒ 6. Formet – tractor Belarus 920, semi-trailer Metalac S-6 of loading capacity of 6t, hydraulic crane Igland 43-65 (reach – 6.5 m, gross lifting capacity – 52 kNm), winch Igland Pronto 6002,

⇒ 7. Formet – tractor Belarus 952, semi-trailer Metalac S-6 of loading capacity of 6t, hydraulic crane Igland 43-65 (reach – 6.5 m, gross lifting capacity – 52 kNm), winch Igland Pronto 6002,

⇒ 8. Vinkum – tractor Belarus 952, semi-trailer Graditelj S-8 of loading capacity of 8t, hydraulic crane Cranab 40-55 (reach – 5.5 m, gross lifting capacity – 56 kNm),

⇒ 9. Vinkum – tractor Steyr 9094, semi-trailer Metal S-8 of loading capacity of 8t, hydraulic crane HDM 340 (reach – 4.8 m, gross lifting capacity – 60 kNm).

Table 1 shows the measured masses of tractor assemblies, tractors and semi-trailers and basic dimensions and turning diameters in accordance with the methods described above.

Based on the presented results, the differentiation of older types of tractor assemblies Pionir can be seen. They have lower masses because they are not equipped with up-to-date cranes, which have a higher mass. Semi-trailers with Pionir tractor assemblies are also less heavy as they have a lower loading capacity (5 tons).

They also differ in size as they have lower length and breadth, but at the same time they are higher than more recent tractor assemblies. The reason of higher height of Pionir tractor assemblies lies in the design of the mechanical crane, which is in fact a fix console so that the winch rope passes through a pulley. More recent tractor assemblies have hydraulic cranes that can be assembled in transport position. Only the tractor assembly Vinkum with the driving means tractor Steyr 9094 is separated due to the redesign of arms of the hydraulic crane HDM 340, because of which the crane cannot be assembled into a proper transport position.

In 1956 Bekker outlays the opinion that the object (vehicle) moving in a media have the tendency of acquiring the form that causes the lowest moving resistance (Horvat et al. 2004B). If the object (vehicle) is presented in the form of a prism, then the ratios H/L (height/length) and B/L (breadth/length) can show significant volume values that are characteristic of each vehicle family. The ratios H/L and B/L are called form indexes and they are used as the initial information on the researched vehicle and its classification in an already known vehicle family. It is characteristic of tractors used for timber extraction (adapted farming tractors, skidders with winch, forwarders), that they are usually in the area under the direction $H = B$.

Form indexes were calculated from the basic dimensions of the researched tractor assemblies and Figure 9 shows their dependence. This Figure also shows the ratio between form indexes of forwarder family according to the research carried out by Horvat et al. (2004B). The survey of form indexes of tractor assemblies and forwarders was given with the aim of comparing the dimensional characteristics of two types of driving means for timber forwarding.

It can be seen that the values of form indexes of all tractor assemblies and forwarders covered by the analysis are under the direction $H = B$, or in other words in the area where height prevails over breadth. It can be observed that form indexes of tractor assemblies have lower values of form index B/L (lower than 0.25) than the forwarder and that they are completely separated from the area of forwarders.

Lower values of form index of tractor assemblies can be explained by their higher length compared to breadth. Lower breadth of tractor assemblies makes them suitable for performing the operations of timber forwarding in thinning stands, as an easier vehicle passage between standing trees in the stand is provided.

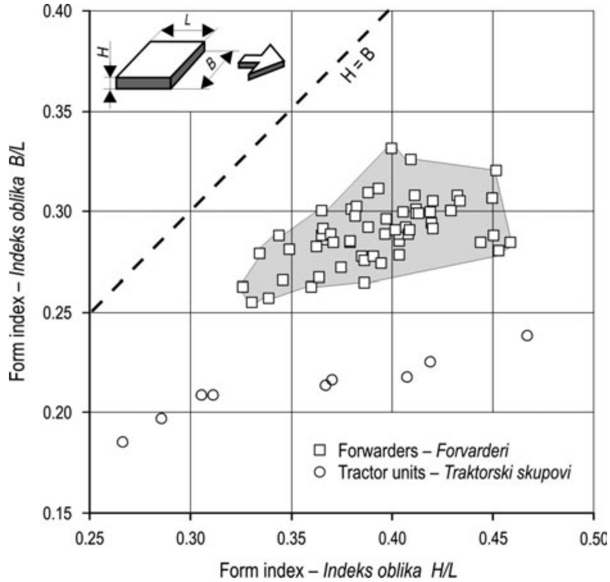

Fig. 9 Dependence of form index *B/L* on form index *H/L*
Slika 9. *Ovisnost indeksa oblika B/L o indeksu oblika H/L*

Higher length implies a larger turning circle of the tractor assembly and hence its poorer manoeuvrability. However the design of the tractor assembly, where the semi-trailer is connected to the tractor by a shaft, enables a large turning angle of the shaft (approximately 60°) from the tractor longitudinal axis, thus providing a lower turning circle and better manoeuvrability of the vehicle. With more recent types of semi-trailers, an additional articulated joint on the shaft enables turning of the semi-trailer longitudinal axis from the tractor longitudinal axis at an angle of 90°.

Based on the analysis of the form index, it can be concluded that tractor assemblies may be treated as a separate family of vehicles for timber forwarding, which is ecologically acceptable for thinning operations owing to its dimensional characteristics.

In further research the measured values were correlated and then subjected to regression analyses. In this procedure, the mass of tractor assemblies was chosen as the independent variable.

Figure 10 shows the dependence of length on mass of the tractor assembly, tractor and semi-trailer. High correlation coefficients and correlation indexes were achieved, which implies a very strong correlation between the independent and dependent variable.

The increase of mass causes the increase of length of the tractor, semi-trailer and tractor assembly. The fastest growth can be seen of the regression curve of length of the tractor assembly with the increase of semi-trailer mass. Although semi-trailers have the lowest mass, their mass has the highest effect on the increase of length of the tractor assembly.

Tractor assemblies are divided into two groups. Older types of tractor assemblies Pionir are characterised by lower masses and lengths. Their position is very close to tractor masses, which can be explained by their light semi-trailers of lower loading capacity and installation of mechanical crane (fix console with pulleys and rope drum), which is supported and leaned on the tractor. More recent types of tractor assemblies have a hydraulic crane installed on semi-trailer of higher mass and load bearing capacity (6 and 8 tons). These tractor assemblies have the highest masses with respect to length. The tractor assembly FMV with the tractor Steyr 964 is singled out in the middle of the regression line due to semi-trailer of lower loading capacity (5 tons).

Dependence of breadth on mass of the tractor assembly, tractor and semi-trailer is shown in Fig. 11. The same trend of the listed data and regression lines can be observed. Tractor assemblies are divided into older and more recent types. Older types of tractor assemblies are characterised by the breadth lower than 2 m due to the use of narrower tractors and semi-trailers of lower loading capacity. With more recent types, two tractor assemblies (Formet with tractor Belarus 952 and FMV with tractor Steyr 964) have the breadth lower than 2 m. The tractors used as the driving means in these assemblies had a narrow track width (narrower tyres), which affected their smaller breadth. As semi-trailers in these assemblies had an additional articulated joint on the shaft and a small breadth, these assemblies were selected as the most suitable for timber forwarding in thinning operations due to exceptionally good manoeuvrability in the stand.

Figure 12 shows the dependence of the smallest turning diameter on the mass of the tractor assembly. From an ecological point of view, smaller turning circle means better manoeuvrability of the vehicle in the stand and consequently lower soil tracking and damage to soil and trees in the stand.

Tractor assemblies have low turning diameters – from 11.8 m to 14.3 m. The smallest turning diameter has been recorded with an old type of tractor assembly Pionir with the driving tractor Tigar 42, and it also has the smallest length of all researched assemblies.

The turning circle diameter increases with the increase of mass of the tractor assembly, which is related to a strong dependence of length on mass of the tractor assembly.

However, under the regression line two more recent types of tractor assemblies of higher mass can be clearly seen. The said assemblies have an articulated joint on the semi-trailer shaft, which enables them to make a very small turning diameter regardless of higher mass and total length.

Dependence of imaginary pressure on the mass of the tractor assembly is shown in Fig. 13. The regression line indicates that the imaginary pressure of the tractor assembly on the ground (forest soil) in-

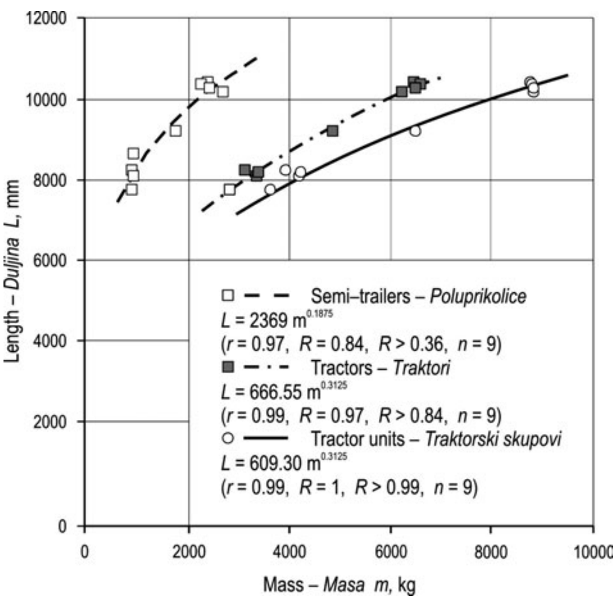

Fig. 10 Dependence of length on mass
Slika 10. *Ovisnost duljine o masi*

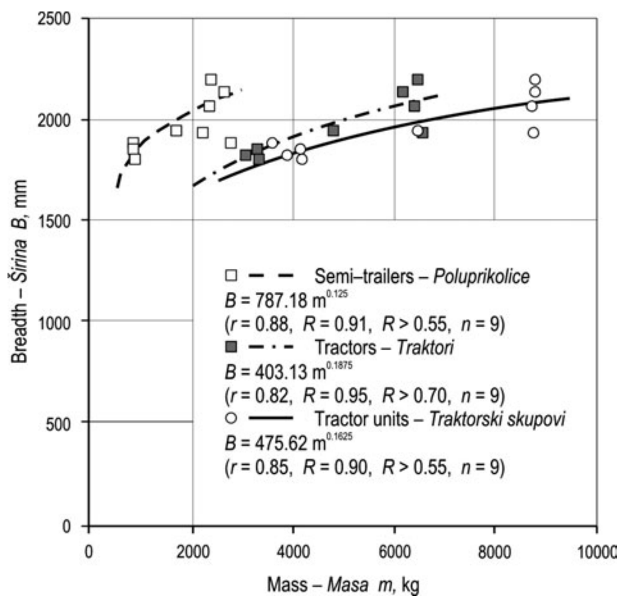

Fig. 11 Dependence of breadth on mass
Slika 11. *Ovisnost širine o masi*

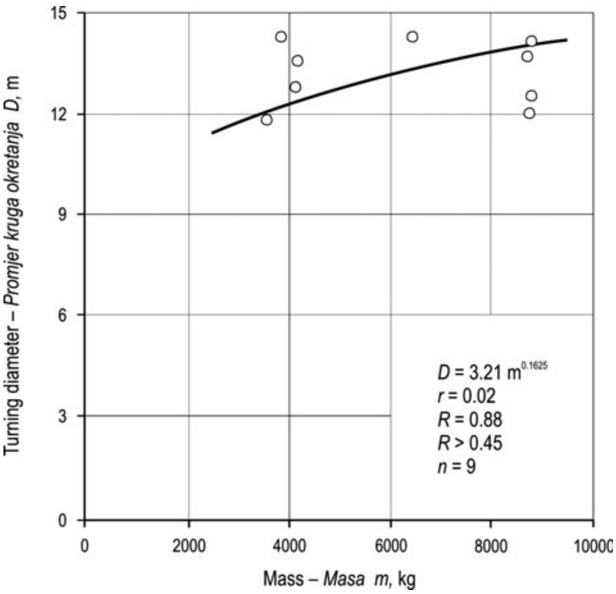

Fig. 12 Dependence of turning circle diameter on mass of tractor assembly
Slika 12. *Ovisnost promjera kruga okretanja o masi traktorskoga skupa*

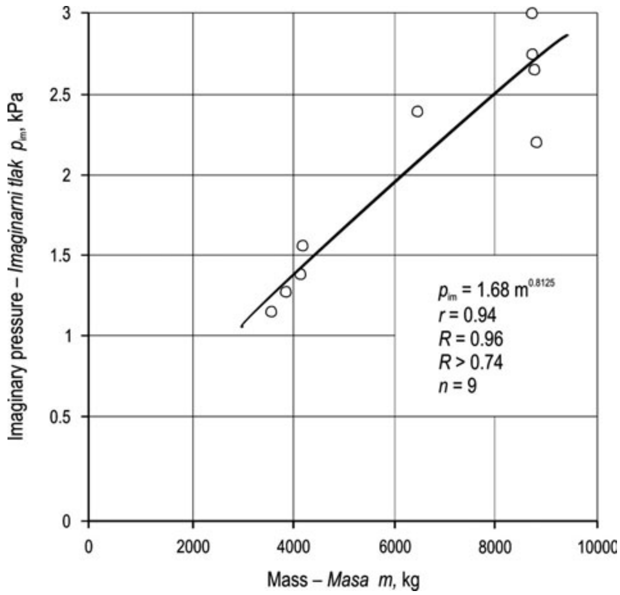

Fig. 13 Dependence of imaginary pressure on mass of tractor assembly
Slika 13. *Ovisnost imaginarnoga tlaka o masi traktorskoga skupa*

creases proportionally with the increase of mass. The values of the imaginary pressure of the tractor assemblies Pionir range between 1.2 kPa and 1.6 kPa. More recent tractor assemblies have imaginary pressures of 2.2 kPa to 3 kPa.

Lower imaginary pressure of the vehicle on the soil means better ecological acceptability, i.e. lower risk of causing damage to forest soil (soil compaction) during the vehicle movement.

4. Conclusions – *Zaključci*

According to the research results Pionir tractor assemblies have very favourable morphological characteristics (low masses and dimensions, small turning diameter, low imaginary pressure on the soil) by which they are classified as ecologically acceptable vehicles for timber forwarding from thinning operations in lowland forests. However, work technology with Pionir tractor assemblies requires from the vehicle to move on the stand so as to approach each processed assortment, which implies higher soil tracking and possibility of causing damage to forest soils of poor bearing strength in lowland areas. Furthermore, out-of-date technical and design solutions (type of crane, older types of tractors) are limiting factors in extending their use primarily due to unfavourable ergonomic and safety requirements.

More recent types of tractor assemblies are characterised by technical designs that ensure environmental suitability in timber forwarding from thinning operations. The problem of higher total length does not affect the vehicle movability as the installation of the articulated joint on semi-trailer shaft ensures small turning diameter and hence reduced risk of causing damage to the standing trees.

The breadth of new tractor assemblies does not differ considerably from Pionir assemblies despite the use of tractors of higher mass and semi-trailers of higher loading capacity. Favourable breadth of tractor assemblies is achieved by use of narrower tyres on rear wheels of the tractor. Better forest accessibility is also provided by the installation of hydraulic cranes whose arms can be assembled during travel.

The installation of the forest winch on the tractor assembly also contributes to ecological suitability of the vehicle. The tractor assembly with winch does not have to move on the stand so as to reach each processed assortment in the reach of the crane. In this way soil tracking is reduced as well as the risk of causing damage to the soil and standing trees.

On the other hand, higher mass of more recent tractor assemblies results in higher imaginary pressure on the soil. However, by comparing imaginary pressures of tractor assemblies and forwarders, it can be concluded that tractor assemblies are more environmentally friendly in timber forwarding under conditions of poor bearing strength of the soil. According to the research carried out by Horvat et al. (2004B) the lowest possible imaginary pressures of

6-wheel and 8-wheel forwarders have the value around 4 kPa. The highest imaginary pressure of the researched tractor assemblies is 3 kPa.

Consequently, more recent types of tractor assemblies, which exert the imaginary pressure on the soil ranging between 2 kPa and 3 kPa are better from the point of view of soil protection and ecological acceptability for the operations performed on forest soils of poor bearing strength.

To conclude, tractor assemblies are considered ecologically more favourable forest vehicles under conditions of poor bearing strength of the soil as well as in thinning operations in lowland forests.

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Sažetak

Morfološka raščlamba šumskih traktorskih skupova

Rezultati ovoga rada prikazuju morfološku raščlambu devet različitih tipova traktorskih skupova koji se koriste u šumarskoj praksi pri izvoženju drva iz proreda nizinskih šuma. Pri tome su zastupljena četiri tipa traktorskih skupova starije proizvodnje Pionir, opremljenih mehaničkim dizalicama. Preostalih pet novijih traktorskih skupova bilo je opremljeno hidrauličnim dizalicama, a od toga su dva još dodatno opremljena dvobubanjskim šumskim vitlima.

Prema rezultatima istraživanja traktorski skupovi Pionir imaju vrlo povoljne morfološke značajke (malu masu i dimenzije, mali promjer kruga okretanja, mali imaginarni tlak na tlo) koje ih svrstavaju u ekološki prihvatljiva vozila za izvoženje drva iz proreda nizinskih šuma. No, tehnologija rada s traktorskim skupovima Pionir zahtijeva kretanje vozila po sastojini do svakoga izrađenoga sortimenta, što znači i veće gaženje tla i mogućnost oštećivanja slabonosivih šumskih tala u nizinskom području. Također, zastarjela tehnička i konstrukcijska rješenja ograničavaju njihovu uporabu zbog nepovoljnih ergonomskih i sigurnosnih zahtjeva.

Noviji tipovi traktorskih skupova ističu se tehničkim rješenjima koja im osiguravaju okolišnu pogodnost pri izvoženju drva iz proreda. Problem veće ukupne duljine ne utječe na kretnost vozila jer se ugradnjom zgloba na rudu poluprikolice osigurava mali promjer kruga *okretanja te time manja opasnost od oštećivanja dubećih stabala. Povoljna se širina traktorskih skupova postiže korištenjem užih guma na stražnjim kotačima traktora. Ugradnjom se šumskoga vitla na traktorski skup smanjuje gaženje sastojine, oštećivanje tla i dubećih stabala.*

Noviji tipovi traktorskih skupova ostvaruju imaginarni tlak na tlo između 2 kPa i 4 kPa te imaju veću prednost za rad na šumskim tlima slabe nosivosti nego forvarderi koji ostvaruju najmanje imaginarne tlakove oko 4 kPa.

Zaključno, traktorske skupove smatramo ekološki povoljnim šumskim vozilima u uvjetima slabe nosivosti tla te rada u proredama nizinskih šuma.

Ključne riječi: traktorski skup, morfološka raščlamba, ekološka pogodnost, izvoženje drva, prorede

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