GDK 377.22+114 (045)=163.6

Ocena grobosti terena za spravilo lesa z vlačilci hlodov z vitlom

Terrain Roughness Evaluation for Timber Extraction by Cable Skidder

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Izvleček:

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Ta članek podaja analizo talnih ovir v Zalesini, eni od gozdnogospodarskih enot (GGU) prebiralnih gozdov v hribovito-goratem predelu Hrvaške, kot del opisa terena in klasifikacije, potrebnih za načrtovanje gozdnih del. V predelu visokega krasa je grobost terena izražena z naklonom, različnimi smermi njegove oblikovitosti in s talnimi ovirami, saj je stanje tal zaradi skeletoidne zgradbe manj pomembno za mobilnost vozil. Podatki, ki so na Hrvaškem na razpolago (pedološki zemljevidi, uradni gozdnogospodarski načrti) in se tičejo talnih ovir (kamnitost/skalnatost, druge ovire pa niso omenjene), so še vedno podani kot delež na področje in kot taki dejansko ne razlikujejo med seboj območij, neprimernih za različna gozdarska vozila. Glede na smernice iz literature so bile talne ovire zabeležene na 319 vzorčnih ploskvah, velikih 10 × 10 m na razdalji 100 m. Na vsaki vzorčni ploskvi sta bili izmerjeni višina in pogostost talnih ovir, ki so bile glede na pogostost razdeljene v štiri skupine: 1) posamezne, 2) redke, 3) zmerno pogoste in 4) pogoste; glede na višino so bili določeni štirje višinski razredi: 1) H20 (10-30 cm), 2) H40 (31-50 cm), 3) H60 (51-70 cm) in 4) H80 (> 71 cm). Na osnovi analize deleža skupin talnih ovir, kotov zmožnosti manevriranja in polmera manevrskega prostora vlačilca, ki opisujejo značilnosti njegove mobilnosti, so bile določene tri nove kategorije grobosti terena: 1) les je mogoče vleči preko talnih ovir (20,14% GGE območja), 2) lesa je mogoče vleči, če obidemo ovire (24,54% GGE območja) in 3) potrebna je gradnja vlak (54,16% GGE območja).

Ključne besede: talne ovire, prevoznost terena, vlačilec, grobost terena

Abstract:

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This paper gives analysis of ground obstacles in one Management unit of selective forests in hilly-pre-mountainous part of Croatia, Zalesina, as one part of terrain description and classification required for planning forestry operations. In the area of high karst, terrain roughness is defined in terms of slope, its various direction forms and ground obstacles as soil condition is of minor importance for vehicle mobility due to highly skeletoid soil composition. Available data (pedological maps, official management plans) in Croatia regarding ground obstacles (stoniness/rockiness while other obstacles are left unmentioned) is still given in terms of share per area and as such does not really differentiate areas unsuitable for various forestry vehicles. According to literature guidelines, ground obstacles were recorded on 319 sampling plots, each of size 10 × 10 m and with 100 m of distance. Height and frequency of ground obstacles were measured on each sample plot and according to frequency were divided into four groups: 1) isolated, 2) infrequent, 3) moderately frequent and 4) frequent; as well as in four height classes: 1) H20 (10-30 cm), 2) H40 (31-50 cm), 3) H60 (51-70 cm) and 4) H80 (> 71 cm). Based on share analysis of ground obstacle groups, manoeuvrability angles and clearance radiuses of skidder which describe its mobility characteristics, three new terrain roughness categories were defined: 1) skidding timber across ground obstacles is possible (20.14% of MU area), 2) skidding timber while by-passing ground obstacles is possible (24.54% of MU area) and 3) construction of skid roads is necessary (54.16% of MU area).

Key words: ground obstacles, terrain trafficability, skidder, terrain roughness

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1 UVOD
1 INTRODUCTION

Terrain trafficability is its ability to support vehicle movement during which terrain characteristics (slope, ground obstacles, soil bearing capacity) affect vehicle mobility (Eichrodt and Heinimann 2001, Suvinen 2006). On the other hand, vehicle mobility is its ability to move in space from point A to point B while retaining its purpose for example timber harvesting or timber transport (Eichrodt 2003, Lubello 2008, Đuka 2014).

Skidders and forwarders are still dominant for timber extraction in most European countries such as Germany, Finland, Sweden, Norway, Slovenia, Italy, Austria, Ireland, Switzerland, Greece, Croatia (Schwaiger and Zimmer 2001, Beuk 2007) and vehicle choice for timber extraction depends on terrain characteristics i.e. terrain slope (FAO/ECE/ILO 1971, Heinimann 1999), ground obstacles (Horn et al. 2007, Olund 2001, Visser and Berkett 2015) and soil bearing capacity (Amishev et al. 2009) as well as primary and secondary forest openness and as such is an important parameter in the whole timber supply chain. Pentek et al. (2010) highlight the importance of shape, position and density of secondary forest network which is critical for basic vehicle-to-timber access during timber extraction (length of winch rope or boom reach). From the strategic level of planning timber harvesting, terrain slope is the most important factor that directly affects the choice of timber harvesting system (Đuka 2014, Đuka et al. 2015) by affecting vehicle stability where all vehicle wheels (tracks) collide with the same macrotophograhic conditions. Same authors conclude that ground obstacles are defined as microtopographic terrain characteristics independent in size and position of macroptopographc terrain parameters and that they affect one or more wheels (tracks) during vehicle movement in forest stand. Ground

Slika 1: Raznolikost talnih ovir v oddelku št. 5 študijskega območja (14,85 ha) (foto: A. Đuka)
Figure 1: Variety of ground obstacles in compartment No. 5 of researched area (14.85 ha) (photo: A. Đuka)

roughness is described independently of slope, and as such is a well-known terrain parameter in forestry classification systems (Eriksson et al. 1975, Rowan 1996, Mellgren 1980, Berg 1992, Owende et al. 2002). Steep terrain slope and/or ground obstacles affect longitudinal and lateral vehicle stability, with that their mobility, productivity and work safety (Visser and Berkett 2015, Visser and Stampfer 2015).

An obstacle is generally defined as any natural or man-made terrain feature that slows, diverts, or stops the movement of personnel or vehicles. The height and spacing of obstacles affect the ride and machine stability and consequently the practical speed of an off-road vehicle. Eriksson et al. (1975) and Berg (1992) state that typical permanent obstacles that slow down off-road vehicles are rocks, boulders, depressions, rock outcrops, soil mounds (higher than 10 cm), cavities (deeper than 20 cm), undulations, sinkholes etc. Boulder quota or block index (stoniness or covered boulders and larger rocks present in the surface layer and down to 20/30 cm) should be field checked or measured on 100 sample plots selected randomly or systematically. Authors conclude that soil probe (used for determining rocks beneath the surface up to 20 cm depth) does not have to be used all the time, but is necessary when planning for site preparation and choice of reforestation method.

In practice the roughness class is usually assessed visually (Eriksson et al. 1975, Mellgren 1980, Berg 1992, Suvinen and Saarilahti 2006), and experienced operator can classify unit by visual assessment while unexperienced operator needs supportive measurements. Löffler (1984) and Rowan (1996) highlight that ground obstacles can be measured on round or squared sampling plots of minimum 100 m^2 area and then are divided into four height classes H20 (10–30 cm), H40 (31-50 cm), H60 (51-70 cm) and H80 (>71 cm). Similar obstacle height division is later done by Owende et al. (2002) in Ecowood project protocol (Table 1).

Heinimann (1999) states it is crucial to know terrain factors affecting vehicle mobility because of their high impact on the whole harvesting system. Same author continues that the base of scientific research of vehicle – terrain system was set by Bekker in 1956 in his book »Theory of Land Locomotion«, which was later extended by other researchers such as Wong (1989) in »Terramechanics and off-road vehicles« and Mastinu and Ploechl (2014) in »Road and Off-Road Vehicle System Dynamics Handbook« (Poršinsky et al. 2016). Mechanics of interaction between geometry of terrain and geometry of vehicle must be defined

Preglednica 1: EcoWood klasifikacija terena (Owende in sod. 2002)
Table 1: EcoWood terrain classification (Owende et al. 2002)

Class	Ground condition	Roughness category						Slope	
		Description	Obstacle height, cm	Obstacle height, cm					
				20	40	60	80		
				Average distance between obstacles, m					
1	Good	Even	H 20	1.6-5 5-16	> 16	> 16	> 16	Gentle	< 8°, 14%
			H 20-40	< 1.6 1.6-5	> 16 5-16	> 16 > 16	> 16 > 16		
2	Average	Uneven	H 40-60	< 1.6 < 1.6	1.6-5 1.6-5	5-16 1.6-5	> 16 > 16	Intermediate	8°-14° 14-25%
			H 40-80	< 1.6 1.6-5	< 1.6 1.6-5	5-16 1.6-5	5-16 5-16		
3	Poor	Rough	H 40-80	< 1.6 < 1.6	< 1.6 < 1.6	1.6-5 < 1.6	5-16 < 1.6	Steep	> 14°, 25%
4	Very poor (not trafficable)								

in any characterization of terrain roughness from the viewpoint of: 1) obstacle crossing, 2) vehicle controllability and 3) ride comfort (Bekker 1969).

Mobility of forestry vehicles used for timber extraction can be described through these parameters: 1) dimensional features: turning radius, weight, center of gravity position, longitudinal and lateral vehicle stability angle, ground clearance, angle of articulation, front axle oscillation, unloading of front axle, payload of rear axle, tires payload (Šušnjar et al. 2010); 2) locomotion system (Uusitalo 2010, Gregov 2012, Marenče 2014, Poršinsky et al. 2016); 3) the ability to overcome ground obstacles (clearance, lateral stability of vehicle) and orientation and slope of terrain (Macdonald 1999, Kühmaier and Stampfer 2010, 4) traction performance: dependence of slip curve, power and actual speed on drawbar pull and soil bearing capacity (Bojanin et al. 1988, Horvat 1993, Šušnjar 2005) and 5) environmental soundness (Košir 1994, Košir 1995). While other authors also refer to: 1) angle of longitudinal and lateral vehicle stability (Alexandrovich 2013, Gibson and Biller 1974), 2) critical load considering longitudinal vehicle stability (Horvat 1990), 3) load distribution on vehicle axles considering terrain slope and direction of movement (uphill or downhill) and load size (Đuka 2014, Đuka et al. 2016), 4) outer and inner vehicle turning radii (Sever 1980) and 5) manoeuvrability angles and clearance radii (Sever and Horvat 1985).

ISO Standards 13861 (2000) define basic dimensional characteristics of skidder, but do not however explain manoeuvrability angles and clearance radii. On the other hand, literature gives only approximate expressions for their calculation due to various construction parameters and vehicle applications (Poršinsky et al. 2016).

The purpose of this research was to give guidelines for terrain roughness evaluation considering timber extraction by a winch skidder, since in Croatia there are no available data bases of ground obstacles from the aspect of forestry vehicles mobility nor does the official Forest Management Bylaw (NN 79/15) regulate the methodology for estimating ground obstacles. Forest management plans do contain descriptions of each management unit and its compartments (sub-compartments) where rockiness is given in percentage i.e. share per area. The reason of such representation of ground obstacles is probably due to the fact that rockiness values are taken from the General soil map in 1:50,000 scale which differentiates six categories of stoniness share per area: 1) < 2%, 2) 3–10%, 3) 11–25%, 4) 26–50%, 5) 51–90%, and 6) > 91% (Bogunović and Rapaić, 1993).

2 MATERIALI IN METODE
2 MATERIALS AND METHODS

Research was conducted in the area of beech and fir selective forests of Gorski kotar (hilly and pre-mountainous part of Croatia), in management unit »Kupjački vrh« at the Training and research forest center »Zalesina« which is managed by the Faculty of Forestry, University of Zagreb. Management unit »Kupjački vrh« is located at 45° 26' N latitude and 14° 53' E longitude of Greenwich. It consists of 278.80 hectares of forests, of which 274.87 ha is stacked forest area. Management unit is divided into 16 compartments and the average growing stock is 446 m^3/ha, with annual increment of 6.25 m^3/ha. MU »Kupjački vrh« is a typical representative of high karst (Anon. 2004) with a centrally located peak from which terrain descends in all exposition types. Terrain is rich in karst phenomenon without a developed hydrological network and with highly skeletoid mechanical soil composition.

Ground obstacles were determined by setting a systematic network of sample plots consisting of 319 measuring areas, with 100 m distance, and 10 × 10 m in size (Figure 2). On each sample plot, according to the methodology of measuring ground obstacles (Eriksson et al. 1975, Löffler 1984 and Rowan 1996) their height and frequency were measured for the purpose of defining categories according to literature guidelines (Mellgren 1980, Löffler 1984, Berg 1992, Rowan 1996). Five surface structure classes (Table 2): 1) very even terrain, 2) slightly even terrain, 3) uneven terrain, 4) rough terrain and 5) very rough terrain were defined depending on ground obstacle frequency and height class (Đuka and Poršinsky 2016) and former classification systems by Löffler (1984) and Rowan (1996). To be more precise, if H20 obstacles are infrequent or if there are obstacles higher than 31 cm (H40 to H80), but isolated – class 1 is chosen; if H20 obstacles are moderately frequent, but no other class is present – class 1 of surface structure is chosen again. However, if H20 obstacles are moderately frequent and other height classes are present (H40 infrequent, H60 and H80 combined) class 2 is the chosen one. Similar type of assessment continues in class 3. Class 4 is defined by similar frequency of obstacles as in class 3, with one exception – H80 obstacles are more common i.e. infrequent rather than isolated (which would redirect assessment to class 3).

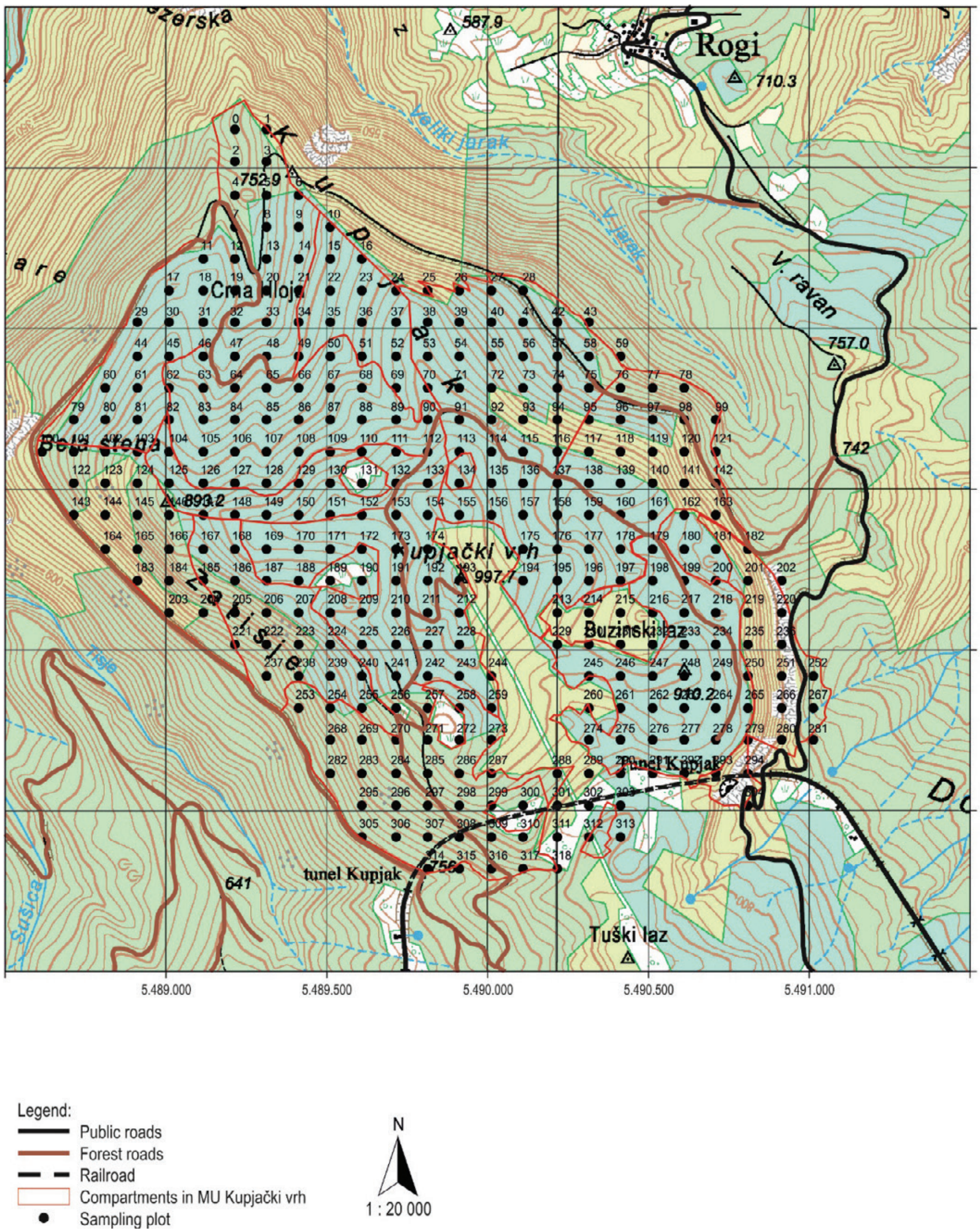
Skidder maneuverability angles (Figure 3A and 3B) impact its mobility not only in movement through the forest stand, for example through bigger terrain depressions (descending or ascending), basins or sinkholes, but also during turning of vehicle, backing skidder for loading/unloading timber, stacking roundwood on landing site etc. Long (frequent), uneven ground obstacles, perpendicular to skidder movement direction will affect its mobility for longitudinal clearance radius value (Figure 3C), while the lowest vehicle point – transverse clearance radius (Figure 3D) should therefore be connected with height of ground obstacles (Poršinsky et al. 2016). Authors further conclude that due to skidder construction parameters they can either drive over ground obstacles (roughness class 1), drive around them (roughness class 2) or by-pass ground obstacles (Krieg et al. 2010, McEwan et al. 2013) while in uneven, rough and very rough terrain conditions (classes 3-5) skid road network should be constructed.

Depending on skidder Ecotrac 120V dimensional features: 1) front axle oscillation ±11°, 2) β_1 approach angle 38°, 3) β_2 departure angle 28°, 4) β_3 break-over angle 50°, 5) R_1 longitudinal clearance radii 806 mm, 6) R_2 transverse clearance radii 734 mm, 7) ground clearance 470 mm and 8) clearance circle 5.1 m, a new reclassification of ground roughness was made for the entire management unit.

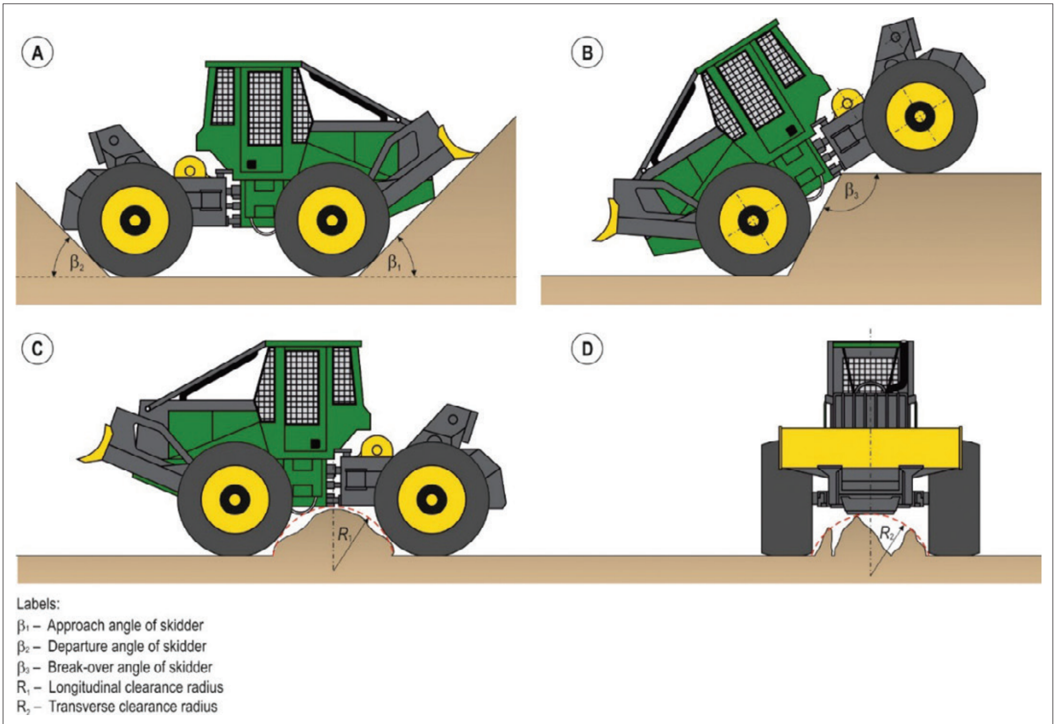
Reclassification on new three classes was based on the fact that the highest/lowest possible ground obstacle which Ecotrac 120V can cross is up/down to 35 cm (based on front axle oscillation ±11° and wheel tread 1.8 m). Approach angle (β_1) of 38° allows obstacle up to 135 cm height/depth, so one can conclude that ground obstacles in height class H20 (10-30 cm) do not represent a threat for vehicle mobility. Descending or ascending of skidder in basins, sinkholes, depressions or similar, is connected to its break-over angle (β_3 50°). Sides of such terrain formations shouldn't have slopes over half of skidder break-over angle i.e. 25°, or vehicle could encounter a so called hang-up failure (Bekker 1969), also sides and bottom of such a basin or depression should

Preglednica 2: Klasifikacija površinske strukture (Löffler 1984, Rowan 1996)
Table 2: Surface structure classification (Löffler 1984, Rowan 1996)

<table>
<tr><th rowspan="2">Surface structure classification</th><th colspan="4">Obstacle height class</th></tr>
<tr><th>H20 (10-30 cm)</th><th>H40 (31-50 cm)</th><th>H60 (51-70 cm)</th><th>H80 (> 71 cm)</th></tr>
<tr><td rowspan="2">1</td><td>Infrequent (41-400 ha^{-1}, 6-16 m)</td><td colspan="3">Other classes combined = Isolated (4-40 ha^{-1}, 17-50 m)</td></tr>
<tr><td rowspan="2">Moderately frequent (401-4000 ha^{-1}, 1.6-5 m)</td><td colspan="3">No other classes present</td></tr>
<tr><td rowspan="2">2</td><td>Infrequent (41-400 ha^{-1}, 6-16 m)</td><td colspan="2">Other classes combined Isolated (4-40 ha^{-1}, 17-50 m)</td></tr>
<tr><td rowspan="3">Frequent (> 4001 ha^{-1}, <1.5 m)</td><td colspan="3">No other classes present</td></tr>
<tr><td>3</td><td rowspan="2">Moderately frequent (401- 4000 ha^{-1}, 1.6-5 m)</td><td rowspan="2">Infrequent (41-400 ha^{-1}, 6-16 m)</td><td>Isolated (4-40 ha^{-1}, 17-50 m)</td></tr>
<tr><td>4</td><td>Infrequent (41-400 ha^{-1}, 6-16 m)</td></tr>
<tr><td>5</td><td colspan="4">All combinations more severe than Class 4</td></tr>
</table>



Slika 2: Vzorčne ploskve na študijskem območju (lastnik vektorskih podatkov: A. Đuka, lastnik topografskega zemljevida: Hrvaška geodetska uprava)
Figure 2: Sampling plots in research area (vector data owner : A.Đuka, topographic map owner: Croatian Geodetic Directorate)



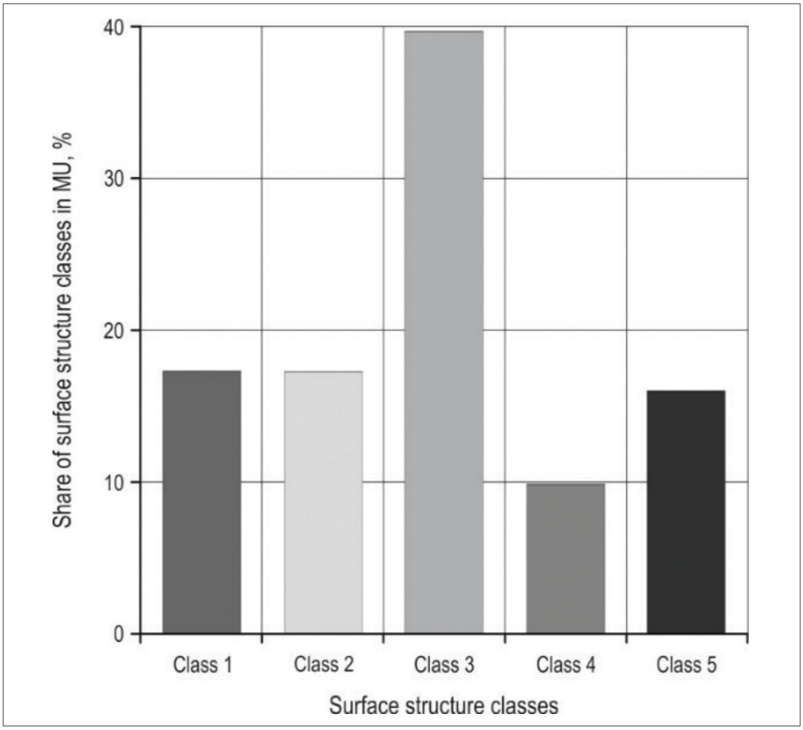
Slika 3: Vpliv kotov zmožnosti manevriranja in polmera manevrskega prostora na mobilnost vlačilca
Figure 3: Impact of maneuverability angles and clearance radiuses on skidder mobility

be at least 2.4 m in length which correlates to wheelbase of this skidder. Departure angle (β_2) affects skidders' movement more during backing up and finding position before loading timber, organizing roadside landing and similar as well as during transition from secondary to primary forest traffic infrastructure, than in driving over ground obstacles (Poršinsky et al. 2016). Bekker (1969) claims that vehicles that have approach and departure angles from 30° to 40° have good off-road characteristics, but Sever and Horvat (1985) state that for cable skidder these values should be between 35° and 50°.

Longitudinal and transverse clearance radii of skidder show their significance in elongated (frequent) ground obstacles transverse in direction to skidder movement, but in this case driving of skidder around ground obstacles, as supposed to driving across them, was established depending on its clearance circle. The differentiation between new roughness classes 2 (by-passing ground obstacles) and 3 (construction of skid road network) was done on the base of ground obstacle height/depth. Everything higher/deeper than 35 cm i.e. classes H40 (31-50 cm), H60 (51-70 cm) and H80 (>71 cm), as well as their frequency: group 3 – moderately frequent (401-4000 No/ha) and group 4 – frequent (4000+ No/ha). So, if ground obstacles of H40, H60 and H80 were moderately frequent or frequent roughness class 3 was chosen, if obstacles were isolated (4-40 No/ha) or infrequent (41-400 No/ha) roughness class 2 was selected.

3 REZULTATI IN DISKUSIJA
3 RESULTS AND DISCUSSION

Analysis of ground obstacles (Figure 4) showed that class 3 (uneven terrain) prevails on most of the management unit area (39.59%) and that classes 3, 4 and 5 together comprise to 65.87% of MU area (Đuka and Poršinsky 2016). Compartment 12 mostly consists of »very even terrain« (class 1) – 36%, whilst compartment 6 (in management plan defined as protective forests) consists in 85% of »very rough terrain« (class 5).



Slika 4: Delež razredov površinske strukture
Figure 4: Share of surface structure classes

When comparing data on rockiness from the management program and surface structure classes from field measurements, discrepancy is noted. Even though surface structure classes do give height and frequency of obstacles, in terms of vehicle mobility, for example skidder during timber extraction, further reclassification was done.

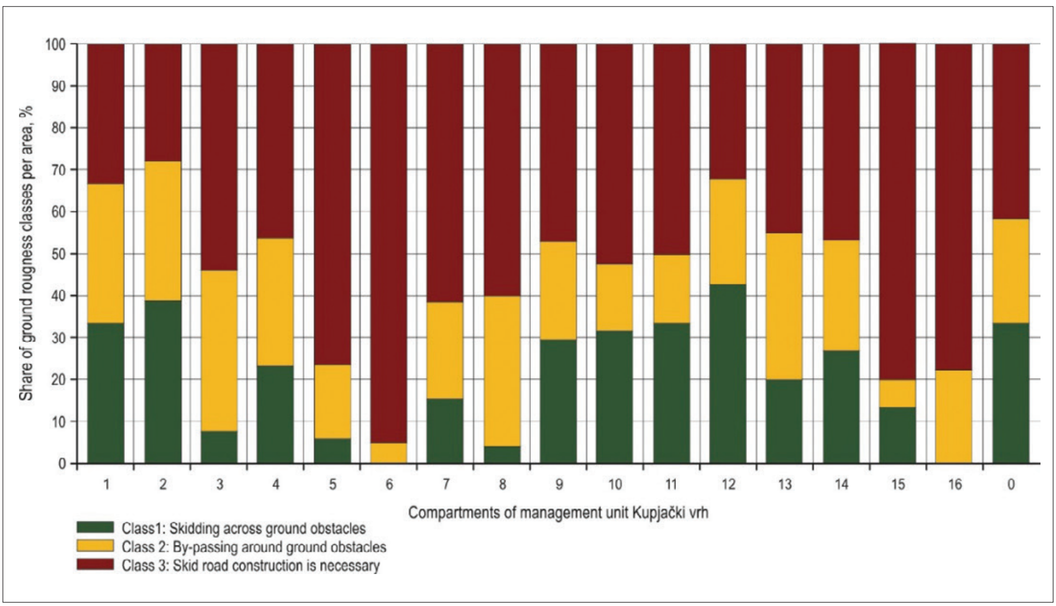
By connecting surface structure classes (1-5) with skidder Ecotrac 120V maneuverability parameters, three new ground roughness classes were defined: 1) skidding timber across ground obstacles, 2) skidding timber while by-passing ground obstacles and 3) skidding timber is possible only on secondary forest traffic infrastructure network (Figure 5).

New ground roughness classification for MU »Kupjački vrh« showed 54.61% share of class 3, 20.14% of class 1 and 24.54% class 2, which concludes that skid roads should be constructed on more than a half of the management unit area. Share of each ground roughness class in every compartment of the management unit is shown in Figure 6. Compartments 3, 5, 6, 7, 8, 10, 11, 15 and 16 have more than 50% of their surface in roughness class 3, while compartments 1, 4, 9, 12, 13 and 14 have more than 30% of area in class 3. The most favourable terrain from the aspect of ground roughness classes and timber skidding is in compartment 2.

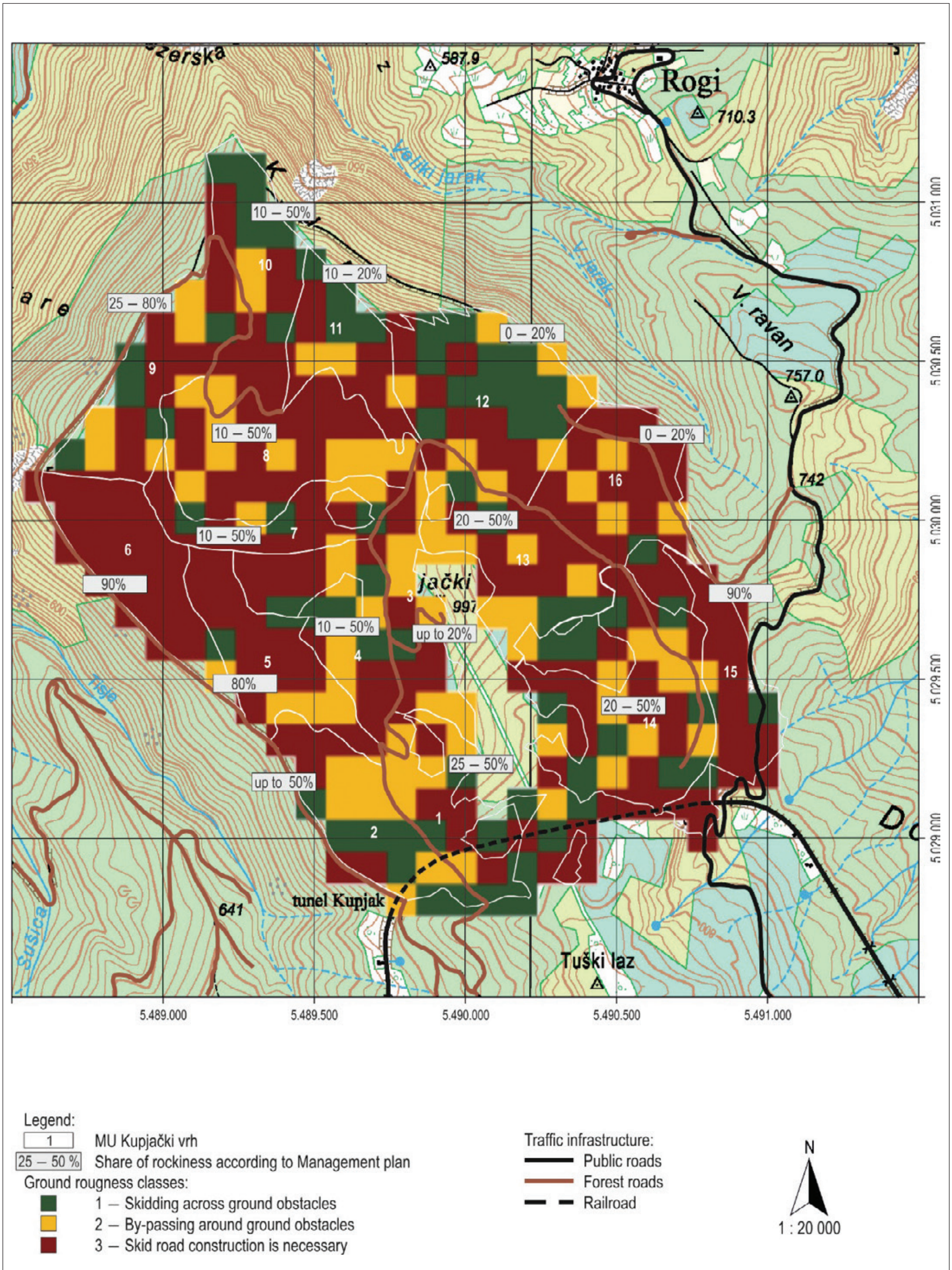
Compartment number zero (0) represents private areas within management unit which are, in agreement with owners, also used for timber transport, and on which research (sampling plots) was also conducted.

When comparing ground roughness classes with data given in Management plan (Figure 7), deviation is again noted. According to Management plan compartments 3, 11, 12 and 16 have the lowest share of rockiness, the highest share per area of rockiness in compartments 5, 6, 9 and 15, while rockiness in all the rest is rounded up to 10(20)-50% of area. What is significant is that height of ground obstacles is still unknown, not to mention depth of surface formations which is not even mentioned.

Slika 5: Razredi grobosti tal (foto: A. Đuka)
Figure 5: Ground roughness classes (photo: A. Đuka)



Slika 6: Delež razredov grobosti tal po gozdnogospodarskih enotah
Figure 6: Share of ground roughness classes in every compartment of management unit



Slika 7: Zemljevid grobosti tal na študijskem območju (lastnik vektorskih in rasterskih podatkov: A. Đuka, lastnik topografskega zemljevida: Hrvaška geodetska uprava)

Figure 7: Map of ground roughness in research area (vector and raster data owner: A. Đuka, topographic map owner: Croatian Geodetic Directorate)

4 ZAKLJUČKI
4 CONCLUSIONS

Conducted research showed that available official data on ground roughness in terms of timber transport is not satisfactory due to the fact that ground obstacles are defined solely as rocks and only in share per area of each compartment. Share of rockiness per area in amount for example 10-50% does not mean much, because height nor depth (of other ground obstacles) is given, so question of vehicle mobility is unknown – will vehicle drive across these obstacles freely, will it be able to go around them, or is construction of skid roads necessary?

The idea of this research was not to state that every ground obstacle should be precisely recorded and measured, because it is a known fact that in practice roughness classes are usually assessed visually (Eriksson et al. 1975, Mellgren 1980, Berg 1992, Suvinen and Saarilahti 2006). The goal was to give guidelines for new reclassification of ground roughness in terms of a cable skidder and its manoeuvrability characteristics. It should be mentioned that, for practical purposes, it would be very helpful if manufacturers would give such information in their technical characteristics booklets which then could be connected by practitioners to terrain conditions.

Even though off-road driving of specialized forestry vehicles is usually prohibited or not recommended in certified forests, researchers and practitioners should have information regarding terrain conditions before entering certain forest stand which would enhance efficiency and promote rationalization (Berg 1992) in forestry altogether. Terrain classification systems are a necessary tool in forestry, since all activities in forests are affected by terrain itself. Recognizing the severity of terrain factors will improve planning and decision making process of all parties involved in forest management.

High definition LiDAR images would certainly be helpful in determining ground roughness conditions (Dubayah and Drake 2000, Reutebuch et al. 2005, Wulder et al. 2008), but this kind of data is still fairly unavailable in territory of Republic of Croatia, as oppose to other European countries such as Finland, Poland, United Kingdom or Slovenia.

If no data on terrain roughness is available, experienced operator can classify unit by visual assessment and the inexperienced one should together with a skilled practitioner during usual operations in forest management determine terrain conditions by using explained sample plots and classification system. By combining manoeuvrability of forestry vehicles and terrain roughness classes derived for those vehicles, planning of harvesting operations should be enhanced.

5 POVZETEK

Ta članek podaja analizo talnih ovir v eni gozdnogospodarski enoti (GGE) Učnega in raziskovalnega gozdarskega centra Zalesina, Hrvaška, kot ene od pomembnih značilnosti terena, ki omejujejo mobilnost vlačilcev med spravilom lesa. Raziskava je bila opravljena na območju bukovih in jelovih prebiralnih gozdov v Gorskem kotarju (hribovitem in goratem predelu Hrvaške). GGE obsega 278,80 hektarjev gozdov, od katerih je 4,87 ha območje gozda s skladovnicami. GGE je razdeljena na 16 oddelkov, povprečna lesna zaloga je 446 m^3/ha, letni prirastek pa 6,25 m^3/ha. Ta GGE je značilna predstavnica visokega krasa s središčno lociranim vrhom, od katerega se teren spušča na vse ekspozicijske načine. Teren je bogat s kraškimi pojavi brez razvitega vodnega omrežja ter ima zelo skeletoidno mehansko sestavo tal. Na takem terenu je grobost izražena z naklonom, različnimi smermi njegove oblikovitosti in s talnimi ovirami ter vpliva na izbiro gozdarskih vozil za spravilo lesa. Podatki, ki so na Hrvaškem na razpolago (pedološki zemljevidi, uradni gozdnogospodarski načrti) in se tičejo talnih ovir (kamnitost/skalnatost, druge ovire pa niso omenjene), so še vedno podani kot delež na področje in kot taki dejansko ne razlikujejo med seboj območij, neprimernih za različna gozdarska vozila. Talne ovire so bile zabeležene na 319 vzorčnih ploskvah, velikih 10 × 10 m na razdalji 100 m. Na osnovi prejšnjih raziskovalnih smernic sta bili izmerjeni višina in pogostost talnih ovir, ki so bile glede na pogostost razdeljene v štiri skupine: 1) posamezne, 2) redke, 3) zmerno pogoste in 4) pogoste; glede na višino so bili določeni štirje višinski razredi: 1) H20 (10-30 cm), 2) H40 (31-50 cm), 3) H60 (51-70 cm) in 4) H80 (> 71 cm). Analiza talnih ovir (Slika 4) je pokazala, da razred 3 (neenakomeren teren) prevladuje na večini površine gozdnogospodarske enote (39,59%) ter da razredi 3, 4 in 5 skupaj obsegajo 65,87% površine GGE.

Nova klasifikacija grobosti tal za celotno gozdnogospodarsko enoto je bila opravljena na osnovi dimenzionalnih lastnosti vlačilca hlodov Ecotrac 120V: 1) nihanje prednje osi ±11°, 2) β_1 kot dostopa 38°, 3) β_2 odhodni kot 28°, 4) β_3 kot prevračanja 50°, 5) R_1 polmeri vzdolžnega manevrskega prostora 806 mm, 6) R_2 polmeri prečnega manevrskega prostora 734 mm, 7) talni manevrski prostor 470 mm in 8) krog manevrskega prostora 5,1 m.

Na osnovi analize deleža skupin talnih ovir, kotov zmožnosti manevriranja in polmera manevrskega prostora vlačilca, ki opisujejo značilnosti njegove mobilnosti, so bile določene tri nove kategorije grobosti terena: 1) les je mogoče vleči preko talnih ovir (20,14% GGE območja), 2) lesa je mogoče vleči, če obidemo ovire (24,54% GGE območja) in 3) potrebna je gradnja vlak (54,16% GGE območja).

Čeprav je vožnja specializiranih gozdarskih vozil izven cest običajno prepovedana ali odsvetovana v certificiranih gozdovih, bi morali raziskovalci in praktični izvajalci imeti informacije o terenskih pogojih, preden se podajo v določen gozdni sestoj. To bi povečalo učinkovitost in spodbujalo racionalizacijo v gozdarstvu (Berg 1992). Visokoločljivostne LIDAR slike bi zagotovo pomagale pri določanju grobosti tal, če pa podatkov o grobosti terena ni, lahko izkušen operater razvrsti enoto na podlagi okularne ocene, neizkušeni pa bi moral skupaj z izkušenim praktičnim izvajalcem med običajnimi aktivnostmi pri gozdnem gospodarstvu določiti terenske pogoje s pomočjo pojasnjenih vzorčnih ploskev in klasifikacijskega sistema.

5 SUMMARY

This paper gives analysis of ground obstacles in one Management unit of Forest training and research center Zalesina, Croatia, as one of important terrain characteristics that limit skidder mobility during timber extraction. Research was conducted in the area of beech and fir selective forests of Gorski kotar (hilly and mountainous part of Croatia. MU consists of 278.80 hectares of forests, of which 274.87 ha is stacked forest area. MU is divided into 16 compartments and the average growing stock is 446 m^3/ha, with annual increment of 6.25 m^3/ha. This MU is a typical representative of high karst with a centrally located peak from which terrain descends in all exposition types. Terrain is rich in karst phenomenon without a developed hydrological network and with highly skeletoid mechanical soil composition. In such terrain, roughness is defined in terms of slope, its various direction forms and ground obstacles and it affects the choice of forestry vehicles during harvesting operations. Available data (pedological maps, official management plans) in Croatia regarding ground obstacles (stoniness/rockiness) is still given in terms of share per area and as such does not really differentiate areas unsuitable for various forestry vehicles. Ground obstacles were recorded on 319 sampling plots, each of size 10 × 10 m and with 100 m of distance. Based on previous research guidelines, height and frequency of ground obstacles were measured on each sample plot and according to frequency were divided into four groups: 1) isolated, 2) infrequent, 3) moderately frequent and 4) frequent; as well as in four height classes: 1) H20 (10-30 cm), 2) H40 (31-50 cm), 3) H60 (51-70 cm) and 4) H80 (> 71 cm). Analysis of ground obstacles (Figure 4) showed that class 3 (uneven terrain) prevails on most of the management unit area (39.59%) and that classes 3, 4 and 5 together comprise to 65.87% of MU area.

Depending on skidder Ecotrac 120V dimensional features: 1) front axle oscillation ±11°, 2) β_1 approach angle 38°, 3) β_2 departure angle 28°, 4) β_3 break-over angle 50°, 5) R_1 longitudinal clearance radii 806 mm, 6) R_2 transverse clearance radii 734 mm, 7) ground clearance 470 mm and 8) clearance circle 5.1 m, a new reclassification of ground roughness was made for the entire management unit.

Based on share analysis of ground obstacle groups, manoeuvrability angles and clearance radiuses of skidder, three new terrain trafficability categories were defined (Figures 6 and 7): 1) skidding timber across ground obstacles (20.14% of MU area), 2) skidding timber while by-passing ground obstacles (24.54% of MU area) and 3) construction of skid roads is necessary (54.16% of MU area).

Even though off-road driving of specialized forestry vehicles is usually prohibited or not recommended in certified forests, researchers and practitioners should have information regarding terrain conditions before entering certain forest stand which would enhance efficiency and promote rationalization in forestry altogether. High definition LiDAR images would certainly be helpful in determining ground roughness conditions, but if no data on terrain roughness is available, experienced operator can classify unit by visual assessment and the inexperienced one should together with a skilled practitioner during usual operations in forest management determine terrain conditions by using explained sample plots and classification system.

6 VIRI
6 REFERENCES

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