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ANALYSIS OF THE QUALITY OF PRIMARY FOREST ACCESSIBILITY: THE CASE STUDY

ANALIZA KVALITETA PRIMARNE OTVORENOSTI ŠUMA: STUDIJA SLUČAJA

Vladimir Petković[1]*, Dane Marčeta[1], Muhamed Bajrić[2]

[1] University of Banja Luka, Faculty of Forestry, Bulevar Vojvode Stepe Stepanovića 75a, 78000 Banja Luka
[2] Univesity of Sarajevo, Faculty of Forestry, Zagrebačka 20, 71000 Sarajevo
*e-mail: vladimir.petkovic@sf.unibl.org

Abstract

Relative forest accessibility percent of accessible forest area by forest roads in comparison with total forest area is the most important indicator of the quality of primary forest accessibility. The accessible forest area by forest roads is determined by the bounded area around forest roads. Today, in the area with steep and variable slopes of terrain, a double targeted geometrical extraction distance of timber is used for the width of the bounded area around forest roads, and the forest road spacing is used in the area with a mild and uniform slope of the terrain. Both parameters depend on the targeted density of forest roads. Modern information technologies (IT) like geographical information systems (GIS) enable the quality spatial and statistical analysis of different kinds of data whose result is not accessible forest areas by current primary forest traffic infrastructure only, but also an insight into the spatial distribution of insufficient accessible areas into the forest area. The spatial distribution of these areas is significant for spatial distribution of the new routes of forest roads. The research is done in the area of Forest Management Unit (FMU) Prosara, for which the spatial analysis of a digital terrain model (DTM) determined the mostly hilly relief area. The average relative forest accessibility, based on double targeted geometrical extraction distance of timber, is 35% for the actual network of forest roads, and targeted forest road spacing is 60% for the upgraded network of forest roads.

Key words: DTM, forest roads, GIS, relative forest accessibility

1. INTRODUCTION / UVOD

Forest accessibility can be expressed by the density of forest roads, average extraction distance, relative forest accessibility and coefficient of efficiency of the forest road network. The density of forest roads is a ratio of the length of forest roads and the total forest area. It is used for the expression of primary forest accessibility for the Forest Management Unit (FMU) and Forest Management Area (FMA).

$$O=D/P$$

Where is:

O-density of forest roads (m/ha or km/1000 ha),

D-length of forest roads (m or km),

P-total forest area (ha or 1000 ha) (Sokolović & Bajrić, 2013).

The impact of forest roads on the value of forest accessibility and density of forest roads depends on their length, their spatial distribution and their suitability for timber extraction. Poršinsky et al. (2017) defined four basic and five spatial criteria for the determination of forest road density. The basic criteria defined the impact of a forest road on its density based on the features, limitations and suitability for timber extraction. The spatial criteria for determination of the impact of forest roads on their density are based on the location of forest road in the forest area. These criteria are used for the determination density of forest roads for the area of a FMU but not for the area of the compartment or sub-compartment.

The second indicator of forest accessibility is the average extraction distance that can be geometrical and real for a theoretic, actual and upgraded network of forest roads. It has an impact on the productivity of means of transport and the costs of transport.

The indicators of the forest accessibility quality are relative forest accessibility and the coefficient of efficiency of forest roads network.

1.1 Relative primary forest accessibility / Relativna primarna otvorenost šuma

Relative forest accessibility was introduced by Backmund in 1966 and it represents the ratio between the accessible forest area and the total forest area. The accessible forest area by forest roads is the area around forest roads so-called bounded area around forest roads which is defined by their width. Backmund used a forest road spacing for the width of accessible forest area, while Sachs (1968) for the width of accessible area around forest roads used 200 m on flat terrain, 100 m on steep terrain for downhill timber extraction, and 200 m for uphill timber extraction. The width of accessible forest area depends on the terrain slope and direction of timber extraction according to Hentschel (1996). He applied a width of the accessible forest area of 150 m for terrain up to 25% slope, 60 m for terrain over 25% slope and for uphill timber extraction, and 100 m for downhill timber extraction. Today, the double average targeted geometrical extraction distance is usually used for the width of accessible forest areas around forest roads. It depends on the targeted density of forest roads (Hayati et al., 2012; Lepoglavec, 2014; Pentek et al., 2005; Petković, 2019; Petković & Potočnik, 2018; Petković et al., 2019; Sokolović & Bajrić, 2013).

Hence the need to define the aims which will contribute to a comprehensive analysis of quality primary forest accessibility:

- Defining the targeted density of forest roads based on terrain characteristics of the observed area,
- Calculation of average targeted geometrical extraction distance and width of the area that makes accessible by forest roads which are used for the width of accessible forest area by forest roads,
- Analysis of relative forest accessibility for the actual network of forest roads,
- Designing the ground lines for new forest roads into the insufficient accessible observed forest area,
- Analysis of relative forest accessibility for the upgraded network of forest roads.

The issue of relative forest accessibility determination is very important since only the data regarding the density of forest roads can be obtained from the Cadaster of forest traffic infrastructure and Forest Management Plans in the Republic of Srpska (RS).

2. MATERIAL AND METHODS / MATERIJAL I METOD RADA

2.1 Research area / Područje istraživanja

The FMU Prosara was selected as a case study which is managed by Forest Administration (FA) Gradiška (Figure 1). It is located in the north of B&H. The total area of the FMU Prosara is 3,812.49 ha, the length of the forest road is 28 km, and the density of forest roads is 7.3 m/ha (IRPC, 2013).

It was necessary to record the forest roads by handheld device for global positioning (GPS) GARMIN 62nd, on the field, from the point of checking their length and density. The relief characteristics of the FMU were obtained by using ESRI ArcGIS 10 software for spatial and statistical analysis of digital terrain model (DTM) with the resolution of 5x5 m and for defining the accessible forest area by forest roads and insufficiently accessible areas at the same time based on the network of forest roads.

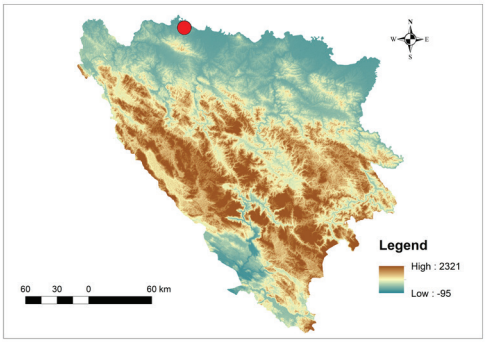

Figure 1. Location of the FMU Prosara in B&H / **Slika 1**. Položaj PJ Prosara u BiH

2.2 Methods of research / Metodi istraživanja

Calculation of relative forest accessibility requires defining the targeted density of forest roads for a specific area. It can be calculated depending on the costs of transport of timber and cutting volume of timber. In addition, the targeted density of forest roads may depend on the intensity of forest management and terrain or relief characteristics of the observed area.

The base for the determination of the targeted density of forest roads is the terrain characteristics of the FMU Prosara since the costs of transport are very changeable at this period of time. Terrain characteristics can be obtained by spatial analysis of DTM. The result of this analysis is the map of relief regions which was obtained based on the classification of elevations according to Bertović (1999).

The targeted density of forest roads is the base for the calculation of the width of accessible forest area by forest roads. The average targeted geometrical extraction distance and targeted forest road spacing will be used as the width of accessible forest area by forest roads. Theaverage targeted geometrical extraction distance is the most often used for defining the width of accessible forest area by forest roads (Backmund, 1966; Hayati et al., 2012; Hentschel, 1996; Lepoglavec, 2014; Pentek et al., 2005; Petković, 2019; Petković & Potočnik, 2018; Petković et al., 2019; Sachs, 1968; Sokolović & Bajrić, 2013).

The average targeted extraction geometrical distance is obtained by the ratio of the average targeted real extraction distance and the average value of the extraction factor. The extraction factor is a factor of geometrical distance increasing due to elevation, slope, and the presence of obstacles at the ground.

$$Sd_{OS} = Sd_{OG} \times k \rightarrow Sd_{OG} = Sd_{OS}/k$$

Where is:

Sd_{OG} - average targeted geometrical extraction distance m,
Sd_{OS} - average targeted real extraction distance m,
k - average value of extraction factor (Sokolović & Bajrić, 2013).

While the average targeted real extraction distance is calculated by Rebula's formula (1981):

$$Sd_{OS} = (k_c/c) \times 10{,}000$$

Where is:
Sd_{OS} - average targeted real extraction distance m,
c - targeted density of forest roads m/ha,
k_c - value of extraction factor for lowland 0.4, hill 0.6 and mountain 0.8.

The second parameter for the definition of the width of accessible forest area by forest road is targeted forest roads spacing and it is inversely proportional to the targeted density of forest roads. This parameter includes the

width of the area which is accessible by forest roads (e) (Hribernik, 2013). It is calculated by the formula:

$$S = 10{,}000/c$$

Where is:
S - targeted forest roads spacing m,
c - targeted density of forest roads m/ha (FAO, 1998; Petković, 2019).

They are then entered into ESRI ArcGIS 10 Geoprocessing tool Buffer for the definition of the bounded area around forest roads which represents accessible forest area by forest roads. This area goes over the border of the FMU and it is necessary to cut these parts of the area by using ESRI ArcGIS 10 Geoprocessing tool Clip at the end (Figure 2). The result is an accessible forest area by forest roads within the boundaries of the FMU.

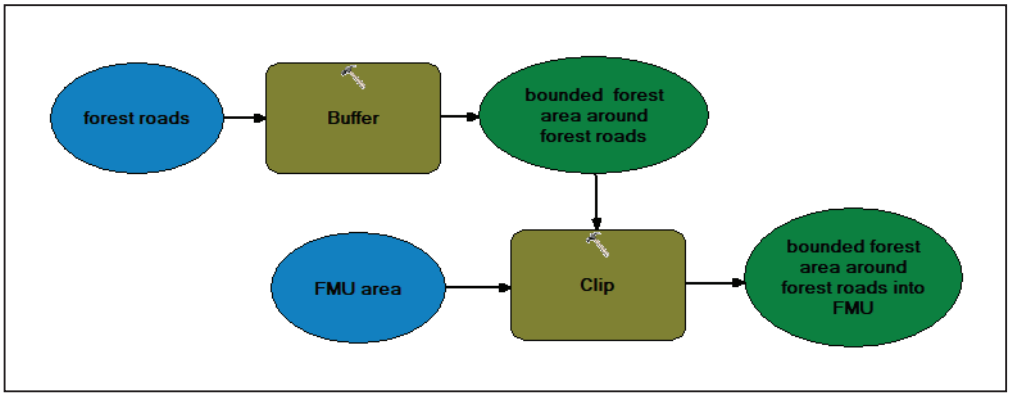

Figure 2. The model of buffer zone creation around forest roads / **Slika 2**. Model kreiranja bafer zone oko šumskih puteva

This area is compared with the total area of the FMU and it is obtained a percent of the FMU area which is accessible by forest roads. It represents the relative forest accessibility O_R.

$$O_R = (P_O/P_U) \times 100$$

Where is:
O_R - relative forest accessibility %,
P_O - accessible forest area by forest roads ha,
P_U - total area ha (Pentek et al., 2005; Petković, 2019; Petković & Potočnik, 2018; Petković et al., 2019; Sokolović & Bajrić, 2013).

The relative forest accessibility can be assessed as insufficient if the percentage of accessible forest area by forest roads is lower than 55% of the total forest area, poor if it is between 56 and 65% of the total forest area, hardly good if it ranges between 66 and 75% of the total forest area, very good if it is between 76 and 85% of the total forest area and excellent if it ranges over 85% of the total forest area (Pentek et al., 2005).

The second importance of the calculation of relative forest accessibility, besides the percentage of accessible forest area by forest roads, is an insight into the spatial distribution of inaccessible forest areas within the boundaries of the FMU. It is necessary to design new forest roads in these areas if we want to make them accessible. These routes for new forest roads are designed as the ground lines with a maximum grade of 8% and 10% for short lengths of ground lines in special terrain conditions at the strategic level of planning of forest roads on the digital map with contours. The purpose of designing ground lines for new forest roads is to achieve the targeted density of forest roads in the FMU and the analysis of relative forest accessibility for the upgraded network of forest roads. This analysis is based on the width of

accessible forest area by forest roads which is equal to the double average targeted geometrical extraction distance (Lepoglavec, 2014) and the targeted forest road spacing.

3. RESULTS / REZULTATI

The two relief regions were obtained by a spatial analysis of the DTM of the FMU Prosara according to Bertović's (1999) classification of elevation. The share of the lowland region in the FMU is 37.5%, and the hilly 62.5% in the FMU. The FMU Prosara is a mostly hilly relief area (Figure 3).

The total length of forest roads, which were recorded by GPS, is 40,130 m in the FMU, and 31,007 m or 77% of the total length of forest roads make forest area accessible. Accordingly the actual forest accessibility is 8.13 m/ha (Table 1). The length of forest roads that make the lowland part of the FMU accessible is 6,813 m, while the hilly part of the FMU is 24,194 m.

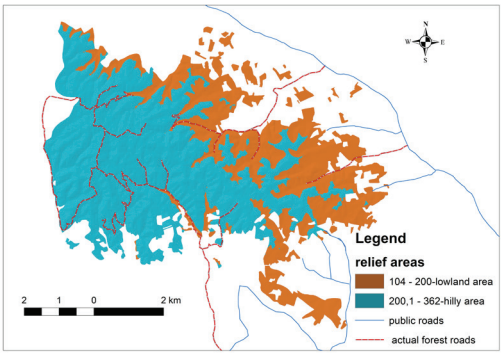

Figure 3. Relief areas in the MU Prosara / **Slika 3**. Reljefna područja u PJ Prosara

Table 1. Current primary forest accessibility (Petković, 2019; Petković & Potočnik, 2018) / **Tabela 1**. Postojeća primarna otvorenost (Petković, 2019; Petković & Potočnik, 2018)

Current forest roads / Postojeći šumski putevi	Total length / Ukupna dužina		The length of segments / Dužina pojedinih dionica			The length of forest roads that make forest accessible / Dužina koja utiče na otvorenost (m)	Actual density of forest roads / Trenutna gustina šumskih puteva (m/ ha)
	Asphalt / Asfaltni (m)	Macadam / Makadamski (m)	Do Not Make Accessible / Ne otvara (m)	Make Accessible from One Side / Otvara jednostrano (m)	Make Accessible from Two-Sides / Otvara obostrano (m)		
Prosara	5,655	34,475	5,696	3,431	27,572	31,007	8.13

The targeted density of forest roads for the lowland relief region is 12 m/ha, while for the hilly region is 18 m/ha (Narodne Novine, 2015). Based on the share of relief regions in the FMU Prosara area, the average value of targeted density is 15.75 m/ha (Table 2).

Table 2. Weighted targeted density of forest roads / **Tabela 2**. Ponderisana ciljana gustina šumskih puteva

Reliefe region / Reljefno područje	Area / Površina		Targeted density /Ciljana gustina (m/ha)	Weighted targeted density / Ponderisana ciljana gustina (m/ha)
	ha	%		
Lowland / Nizijsko	1,429.68	37.5	12	4.5
Hilly / Brdsko	2,382.81	62.5	18	11.3
Total / Ukupno	3,812.49	100		15.75

The targeted average real extraction distance would be 317.46 m, and the targeted average geometrical extraction distance would be 233.43 m since the value of weighted extraction factor is 1.36 (Table 3) for the FMU Prosara. It was obtained by the multiplication of the extraction factors for lowland 1.20 and hilly 1.45 relief regions (Lepoglavec, 2014) and their share in the total area of the FMU.

Table 3. Value of skidding factor for FMU Prosara / **Tabela 3**. Vrijednost faktora privlačenja za PJ Prosara

Relief region / Reljefno područje	Area / Površina		Value of extraction factor / Vrijednost faktora privlačenja	Weigthed extraction factor / Ponderisani faktor privlačenja
	ha	%		
Lowland / Nizijsko	1,429.68	37.5	1.20	0.45
Hilly / Brdsko	2,382.81	62.5	1.45	0.91
Total / Ukupno	3,812.49	100		1.36

The targeted forest road spacing is 635 m based on the average value of the targeted density of forest roads.

The accessible forest area by forest roads is 1,153 ha for double targeted geometrical extraction distance (466.87 m) and 1,527 ha for targeted forest road spacing (Figure 4). The relative forest accessibility ranges between 30 and 40% and it is considered insufficient (Pentek, 2005).

It is necessary to increase the actual density of forest roads by 8 m/ha to achieve a minimum density of forest roads for optimal forest management regarding the relief characteristics of the FMU. This means that it is necessary to design 30,500 m of new forest roads.

24,572 m (Figure 4) of new forest roads or 80.6% of the needed total length is designed, 97.5% of which makes the forest accessible by forest roads from two sides (Table 4).

The total length of the upgraded network of forest roads is 55,579 m based on the length of actual (31,007 m) and proposed (24,572 m) forest roads that make forest accessible. Based on it, the achieved density of forest roads is 14.6 m/ha.

The accessible forest area by forest roads for double average targeted geometrical extraction distance (466.86 m) is 2,029.56 ha, while for targeted forest roads spacing (635 m)

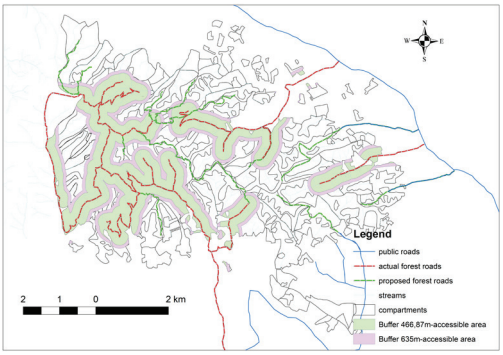

Figure 4. Accessible forest area by actual forest roads and proposed forest roads in insufficently accessible forest areas / **Slika 4**. Otvoreno šumsko područje za postojeće šumske puteve i predloženi šumski putevi u nedovoljno otvorenim šumskim područjima

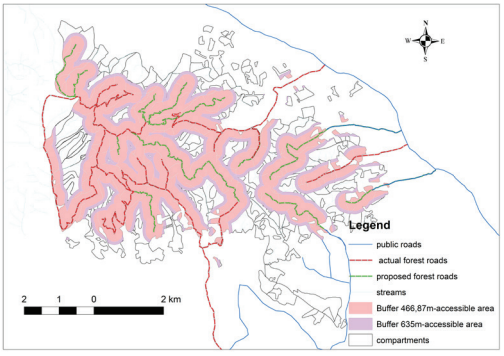

Figure 5. Accessbile areas around the upgraded network of forest roads / **Slika 5**. Otvorene površine oko nadograđene mreže šumskih puteva

Table 4. Proposed forest roads / **Tabela 4**. Predloženi šumski putevi

Proposed forest roads / Predloženi šumski putevi	Total length / Ukupna dužina		The length of segments / Dužina pojedinih dionica			The length of forest roads that make forest accessible / Dužina koja utiče na otvorenost (m)
	Asphalt / Asfaltni (m)	Macadam / Makadamski (m)	Do Not Make Accessible / Ne otvara (m)	Make Accessible from One Side / Otvara jednostrano (m)	Make Accessible from TwoSides / Otvara obostrano (m)	
57-59	-	2,200	-	624	1,576	2,200
57-58	-	1,000	-	-	1,000	1,000
54-26/1	-	596	-	-	500	596
25-25/2	-	1,775	-	-	1,200	1,775
54/1-32	-	5,412	-	-	945	5,412
54/1-53	-	1,413	-	-	-	1,413
54/1-49	-	3,272	-	-	-	3,272
54/1-50	-	2,124	-	-	-	2,124
43-42	-	504	-	-	-	504
34/1-38	-	2,435	-	-	-	2,435
36	-	880	-	-	-	880
40-42	-	2,961	-	-	-	2,961
Total / Ukupno	-	24,572	-	624	23,948	24,572

is 2,582.90 ha. Accordingly, the relative forest accessibility for the upgraded ranges from 53 to 67.7%, which is insufficient and hardly good accessibility.

4. DISCUSSION AND CONCLUSIONS / DISKUSIJA I ZAKLJUČCI

The importance of relative forest accessibility is the percentage of accessible forest area by forests roads at first, but the most important is the percentage of the total forest area which remains outside the influence of forest roads. Those are areas in the forest area that are insufficiently accessible and it is necessary to make them accessible by new forest roads. The base for the calculation of the relative forest accessibility is a forest area accessible by forest roads which depends on its width, and the most often indicator of the width of accessible forest area is double average targeted geometrical extraction distance and the targeted forest road spacing is used for the width.

There are not many differences between the results of the analysis of relative forest accessibility based on the width of accessible forest area by forest roads depending on double targeted geometrical extraction distance and targeted forest road spacing, but it should be applied one or another parameter depending on relief conditions. The most important task in the case of using double-targeted geometrical extraction distance for the width of accessible forest area by forest roads, in the area with steep and variable slopes of the terrain is the determination of the extraction factor. The real extraction distance depends on it, and the costs of transport depend on the real extraction distance.

The targeted geometrical extraction distance and targeted forest road spacing depend on the targeted density of forest roads and it is necessary to define it. The targeted density of forest roads in this case should be 15.75 m/ha based on relief conditions. Petković & Potočnik (2018) and Petković (2019) determined that the targeted density of forest roads should be 16.5 m/ha based on the costs of transport or 17.47 m/ha according to the data obtained by IRPC & Šuma plan d.o.o. (2019). Differences between these results range from 0.7 to 1.8 m/ha. The density of forest roads for the upgraded forest road network is 14.6 m/ha and it is 1.15 m/ha lower than targeted. The density of the forest roads for the upgraded network is around 10 m/ha in lowland and 17.3 m/ha in hilly terrain conditions. It means that the targeted density of forest roads is almost achieved in hilly terrain conditions.

These comprehensive spatial and statistical analyses can be done by using GIS software. These require quality data that can be obtained from forest management plans, field research, DTM, and other sources of data.

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Sažetak

Kvalitet primarne otvorenosti šuma se može najbolje prikazati relativnom otvorenošću, odnosno procentom otvorene površine šuma u odnosu na ukupnu površinu. Površina otvorenog područja šuma predstavlja područje oko šumskih puteva koje karakteriše jednaka udaljenost njegovih granica od šumskih puteva. Površina otvorenog područja zavisi od njegove širine i dužine šumskih puteva. Širina otvorenog područja oko šumskih puteva zavisi od ciljane gustine šumskih puteva jer se na osnovu nje mogu izračunati prosječna ciljana geometrijska daljina privlačenja, koja se danas najčešće koristi kao širina, i ciljano rastojanje između šumskih puteva. Savremene informacione tehnologije, kao što je geografsko informacioni sistem (GIS), omogućavaju kvalitetnu prostornu i statističku analizu različite vrste podataka, čiji rezultat nije samo površina otvorenog područja šuma, nego i uvid u područja koja su nedovoljno otvorena. Raspored nedovoljno otvorenih površina šumskog područja je značajan za prostorno raspoređivanje novih trasa šumskih puteva. Istraživanje je izvršeno u području privredne jedinice (PJ) Prosara. Analizom digitalnog modela terena (DMTa) pomoću ESRI ArcGIS 10 programa, utvrđeno je da se radi o pretežno brdskom području. Trenutna gustina šumskih puteva iznosi 8,13 m/ha, a ciljana za terenske uslove predmetne PJ trebalo bi da bude 15,75 m/ha. Prema tome, prosječna ciljana geometrijska daljina privlačenja treba da iznosi 233,43 m, a ciljano rastojanje između šumskih puteva 635 m. Relativna otvorenost, određena za širinu otvorenog područja koja je jednaka dvostrukoj prosječnoj ciljanoj geometrijskoj daljini privlačenja od 466,86 m i ciljanom rastojanju između šumskih puteva, je nedovoljna i kreće se u prosjeku od 30 do 40% za postojeću mrežu šumskih puteva. Iz tog razloga, projektovano je 24,6 km novih šumskih puteva na digitalnoj karti sa izohipsama u područjima koja su nedovoljno otvorena. Time je dostignuta gustina šumskih puteva od 14,6 m/ha. Relativna otovrenost za nadograđenu mrežu šumskih puteva određena na osnovu širine otvorenog područja koja je jednaka dvostrukoj ciljanoj geometrijskoj daljini privlačenja je nedovoljna 53% ili jedva dobra 68% za ciljano rastojanje između šumskih puteva. Razlike koje se javljaju u relativnoj otvorenosti, odnosno površini šume koja je otvorena, mogu se objasniti neophodnošću primjene faktora privlačenja drveta kod redukovanja stvarne na geometrijsku daljinu privlačenja u brdsko-planinskim reljefnim uslovima sa promjenljivim nagibom terena. Iz tog razloga, primjena ova dva parametra zavisi od reljefnih uslova određenog područja.

Ključne riječi: DTM, GIS, relativna otvorenost, šumski putevi