Analysis of an existing forest road network

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Abstract

Given the need to improve the Croatian forest road networks and the severe constraint on the resources needed to plan these improvements, it is important to target these efforts based upon the available information. Previous research based on existing forest compartment and road network data produced the concept of a methodological study of forest accessibility. Six optimisation stages were defined. This paper deals with the first stage – ***Analysis of the existing primary forest road infrastructure network****. This stage analyses the quantity and quality of the existing forest road network. The results of this analysis, obtained by use of Geographic Information System (GIS), help the forest manager to allocate efficiently the resources to specific forest areas. The results of the analysis are based on data that are easily obtained with GIS. The analysis model is sensitive to the situation on the ground and yet easily implemented. GIS measures of skidding distance, skidding costs and desirable accessibility are included in the model. Relative accessibility and forest road network efficiency are two important calculated results. The paper presents a detailed description of each step of this work stage. The process is demonstrated on two mountainous Management Units within the Forestry Office Opatija, Forest Administration Buzet.*

Key words: *forest roads, forest road network, accessibility, skidding distance, skidding costs, wood transport.*

1. Introduction and scope of research – *Uvod i problematika istraživanja*

The problem of providing quality access to the forests of Croatia and the lack of established direction for carrying out the planning and analysis tasks inspired us to create a protocol for forest accessibility. There is a demand for quality access and costs for providing such high quality access are potentially high. Past solutions have mostly failed to meet the present requirements. This protocol represents the means by which studies of specific forest areas can be done. Its flexibility enables its wide use according to the needs and features of the area to which it is applied. At the same time, it defines global work guidelines, recommended technologies, techniques, methods and mathematical algorithms.

In our previous work, we have defined stages for creating a comprehensive optimized forest road network. We have prepared data flow diagrams for each stage to be used as the basis for highly automated procedures of forest access analysis.

The first task defines the problem and establishes the reasons for the existence of the road network within a Management Unit. Here we describe the basic function of forest stands, the method of management and the design of the computer database.

The work stages of the road network analysis are as follows:

1. Analysis of the existing primary forest road infrastructure,
2. Determination of potential routes of future forest roads,
3. Analysis of possible future forest roads and of the possibility for achieving the desired accessibility,
4. Optimization of the network of forest roads by using a digital elevation model,
5. Checking the viability of the model on the terrain and providing project documentation.

The first stage of work, ***Analysis of the existing primary forest road infrastructure***, consists of various operations and procedures whose main task is to determine the quality, quantity and shortcomings of the existing road network.

2. Methods and results of research – *Metode i rezultati istraživanja*

The paper also deals in details with the first stage of optimization and presents its specific use in two mountainous Management Units of the Forestry Office Opatija, Forest Administration Buzet.

2.1. The first stage of optimization: analysis of the existing primary forest road infrastructure network – Prva faza optimiziranja: raščlamba postojeće mreže primarne šumske prometne infrastrukture

We have defined the following components of the first stage of optimization:

- **1.1. Determining the average existing real mean skidding distance:**
  - Determining the centre of gravity of each subcompartment,
  - Determining the existing geometrical mean skidding distance of each subcompartment,
  - Defining the size of factors of wood assortment skidding for the opened area,
  - Calculation of the real mean skidding distance of each subcompartment,
  - Finding the average existing real mean skidding distance for the whole opened area;
- **1.2. Determining the existing costs of wood skidding:**
  - Calculation of unit skidding cost productivity of each subcompartmet,
  - Calculation of total skidding cost of each subcompartment and total skidding costs of the Management Unit;
- **1.3. Calculation of the average aimed geometrical mean skidding distance:**
  - Defining the average aimed real mean skidding distance,
  - Defining the size of factors of wood assortment skidding for the opened area,
  - Calculation of the average aimed geometrical mean skidding distance;
- **1.4. The analysis of the relative openness for the calculated average aimed real mean skidding distance:**
  - Laying bordered areas of the so-called »buffers« around road network (forest and public),
  - Calculation of the relative openness for the calculated average aimed real mean skidding distance,
  - Determining inefficient areas (the so-called »dead zones«),
  - Calculation of the forest road network efficiency coefficient,
  - Evaluation and comment of the relative openness of the researched area and the forest road network efficiency coefficient;
- **1.5. Defining and separating unopened areas.**

2.1.1. Determining the average existing real mean skidding distance – *Određivanje prosječne postojeće stvarne srednje udaljenosti privlačenja*

The existing mean skidding distance is determined by the use of the centre of gravity method on maps in a digital form. We determined the centre of gravity for each subcompartment by a computer and then, a connecting line was drawn between the centre of gravity and the closest road. It represented the existing geometrical mean skidding distance which

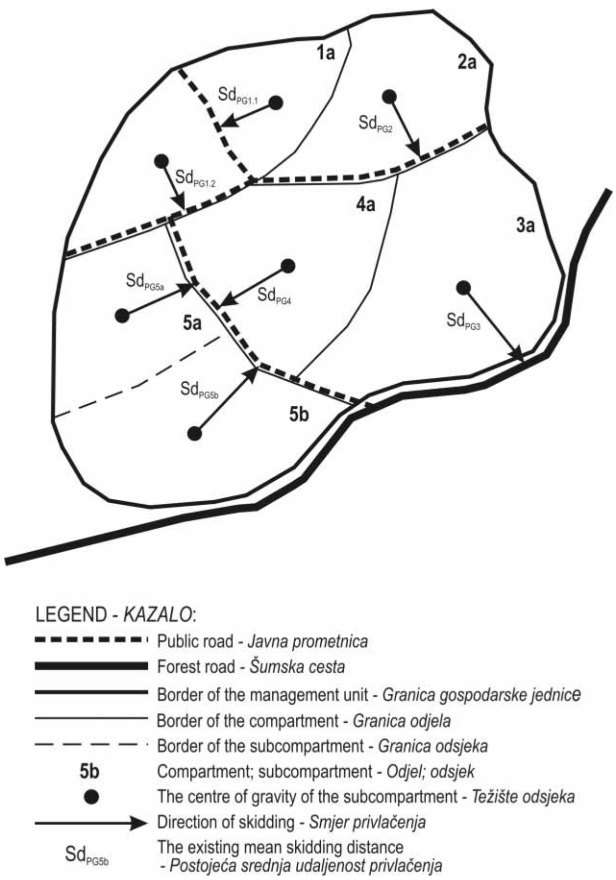

Figure 1 The scheme of determining the existing geometrical mean skidding distances of the subcompartment

Slika 1. *Shematski prikaz određivanja postojećih geometrijskih srednjih udaljenosti privlačenja odsjeka* has to be corrected by a correction factor of wood assortment skidding in order to get the existing real mean skidding distance.

Since according to Segebaden (1964, 1969) in Sweden, the factor of wood assortment skidding was defined in the range from 1.2 (low-lying area) till 1.5 (mountainous area), and according to Abegg (1978) in Switzerland in the range from 1.15 (plain) till 1.65 (mountain) averaging 1.44, in modelling we have taken into calculation the average value of the factors of wood assortment skidding, which these two authors had determined for the mountain $k_g = 1.58$.

The formula for calculating the existing real mean skidding distance of the certain subcompartment is:

$$Sd_{PS} = Sd_{PG} \cdot k_G$$

Legend:

Sd_{PS} – existing real mean skidding distance (m), Sd_{PG} – existing geometrical mean skidding distance (m), k_G – factor of wood assortment skidding.

The average existing real mean skidding distance of the Management Unit is determined as an arithmetical mean of the existing real mean skidding distances of the subcompartment and the expected volume of cut (skidded) wood of each subcompartment will be taken as weights, according to the formula:

$$\overline{Sd}_{PS(i)} = \frac{\sum_{i=1}^{n} Sd_{PS(i)} \cdot E_i}{\sum_{i=1}^{n} E_i}$$

Legend:

$\overline{Sd}_{PS(i)}$ – average existing real mean skidding distance of the Management Unit (m), $Sd_{PS(i)}$ – existing real mean skidding distance of the subcompartment (m), E_i – expected volume of cut (skidded) wood of the subcompartment (m^3), n – total number of subcompartments.

The average existing real mean skidding distance for Management Unit Lisina is 341 m, and for Management Unit Veprinačke šume 344 m.

2.1.2. Determining the existing wood skidding costs – *Određivanje postojećih troškova privlačenja drva*

In order to calculate total costs of wood skidding, after determining the real mean wood skidding distance, it was necessary to calculate unit costs of wood skidding.

Data on the skidding productivity of beech roundwood by a cable skidder LKT 81T (figure 2A) were taken from the research paper published by Vondra and Martinić (1989)

For determining the machine rate of skidder depending on the annual utilization, the calculations of machines cost were used of the Division of Forest Techniques of the Austrian Federal Forest Research Centre of the Federal Ministry of Agriculture Forestry Environment and Water Management (FBVA 2000). According to the calculation, based on 1400 operating hours a year, the machine rate of LKT 81T amounts to EUR 21.15 per PMH (figure 2B).

The relation of machine rate (C, EUR/PMH) and its productivity (P, m^3/PMH) represents the unit cost of production (c, EUR/m^3), i.e. the cost of wood skidding (figure 2C).

Table 1 Total annual costs of wood skidding, building and maintaining of forest roads, the average existing real mean skidding distance and the primary forest openness per Management Units

Tablica 1. *Ukupni godišnji troškovi privlačenja drva, izgradnje i održavanja šumskih cesta, prosječna postojeća stvarna srednja udaljenost privlačenja i primarna otvorenost šuma po gospodarskim jedinicama*

	Manag. unit – *Gospod. jedinica*		Total – *Ukupno* (Average – *Prosječno*)
	Lisina	Veprinačke šume	
Forest road length, km – *Duljina šumskih cesta, km*	21.48	17.71	39.19
Public road length, km – *Duljina javnih cesta, km*	14.68	16.94	31.62
Total road length, km – *Ukupna duljina cesta, km*	36.16	34.65	70.81
Total openness, km/1000 ha – *Ukupna otvorenost, km/1000 ha*	23.72	17.76	(20.38)
Average existing real mean skidding distance, m *Prosječna postojeća stvarna srednja udaljenost privlačenja, m*	341	344	(343)
Annual cost of wood skidding, EUR – *Godišnji trošak privlačenja drva, EUR*	24196	31270	55466
Annual cost of forest road building, EUR – *Godišnji trošak izgradnje šumskih cesta, EUR*	16960	13990	30950
Annual cost of forest road maintenance, EUR – *Godišnji trošak održavanja šumskih cesta, EUR*	13317	10980	24298
Total anual costs of wood transport, EUR – *Ukupni godišnji troškovi transporta drva, EUR*	54473	56240	110713

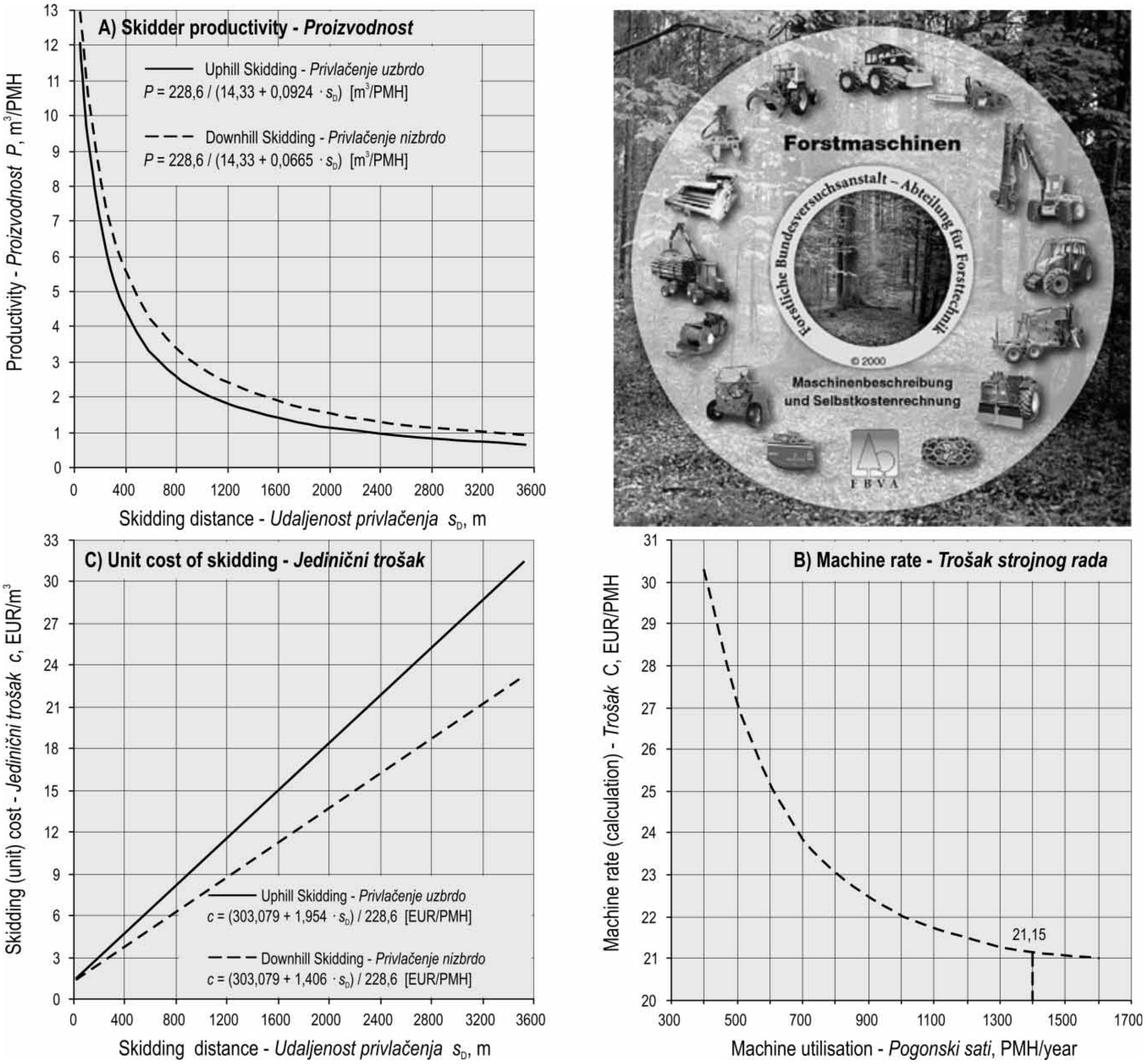

Figure 2 Performance of timber skidding by cable skidder LKT 81T

Slika 2. *Prikaz parametara privlačenja drva zglobnim traktorom LKT 81T*

Using the algorithms for each individual real mean skidding distance, depending on the wood skidding direction, we can calculate the unit skidding cost.

The total cost of wood skidding for a specific forest area (subcompartment) can be calculated as a product of a unit wood skidding cost and the expected volume of cut wood by using the following mathematical expression:

$$UT_{p(i)} = c \cdot E_{(i)}$$

The total skidding cost for the whole Management Unit as the sum of total skidding costs of all subcompartment according to the formula:

$$ST_p = \sum_{i=1}^{n} UT_{P(i)}$$

Legend:

$UT_{P(i)}$ – total skidding cost of an individual subcompartment (EUR), c – unit skidding cost (EUR/m^3), ST_P – total skidding cost of the whole Management Unit (EUR), $E_{(i)}$ – expected volume of cut (skidded) wood of the individual subcompartment (m^3).

In order to calculate the costs required for building and maintaining forest roads, we used the data of the Forest Administration Buzet on prices of building and maintaining forest roads on the researched area. For defined input parameters we calculated: the annual building cost of 1 m of a forest road in the amortization period of 40 years is 0.79 EUR/m a year and the annual cost of maintaining 1 m of a forest road in the same amortization period is 0.62 EUR/m a year.

2.1.3. The aimed geometrical mean skidding distance – *Ciljana geometrijska srednja udaljenost privlačenja*

The average aimed geometrical mean skidding distance is calculated in a way to first determine the average aimed real mean skidding distance which depends on a great number of influential factors.

Rebula (1981) in his model of determining the optimum openness used the following mathematical expressions (in the calculation we have not taken into account the secondary profit from the forest road network since we could not have defined it unambiguously).

$$O_{FR-O} = 100 \cdot \sqrt{\frac{E \cdot T_P \cdot f \cdot k_S}{T_A + T_O - d_S \cdot E}}$$

$$Sd_{OS} = \frac{k_S}{O_{FR-O}} \cdot 10000$$

Legend:

$O_{FR\text{-}O}$ – optimum openness of the forest area (m/ha), Sd_{OS} – optimum real mean skidding distance (m), E – average annual quantity of skidded wood assortments from 1 ha (m^3/ha), T_P – variable cost of skidding 1m^3 of wood assortments at the distance of 1 m (EUR/m^3m), F – factor of the walking cost, k_S – total correction factor of the theoretical mean skidding distance, T_A – average annual amortization of 1m of a forest road (EUR/m), T_O – average annual maintenance cost of 1 m of a forest road (EUR/m), d_S – secondary profit from the forest road network (EUR/m^3).

The model of calculation of optimum openness (Rebula 1981) has been used to determine the average (Sd_{CS}) aimed geometrical mean skidding distance based on the average aimed real mean skidding distance. (introducing skidding factors of wood assortments). The aimed optimum openness has also been calculated by the use of the mathematical expression.

The total correction factor of the theoretical mean skidding distance (k_S) enables the use of the theoretical model, which includes the parallel and equal distribution of forest roads, in areas where such a distribution is not possible (hilly and mountainous areas).

Table 2 The relation between the optimum openness and the average aimed real mean skidding distances according to formulas of Rebula (1980) for various total correction factor of the theoretical mean skidding distance

Tablica 2. *Odnos optimalne otvorenosti i prosječne ciljane stvarne srednje udaljenosti privlačenja prema formulama Rebule (1980.) za različiti sveukupni čimbenik korekcije teoretske srednje udaljenosti privlačenja*

$O_{FR\text{-}O}$, m/ha	k_S=0.70	k_S=0.75	k_S=0.80	k_S=0.85	k_S=0.90
	Sd_{CS}, m				
27	259	278	296	315	333
28	250	268	286	304	321
29	241	259	276	293	310
30	233	250	267	283	300
31	226	242	258	274	290
32	219	234	250	266	281
33	212	227	242	258	273
34	206	221	235	250	265
35	200	214	229	243	257

Together with the network correction factor it includes the correction factor of skidding wood assortments (for the transformation of the geometrical mean skidding distance into the real mean skidding distance of wood).

FAO (1974a and 1974b) defines the total correction factor of the theoretical mean skidding distance for mountains in the range from 2.8 to 3.6 and for very steep mountains higher than 3.6. Our research Management Units are situated in the mountainous areas rich with Karst phenomena (which influence the increase of the total correction factor of the theoretical mean skidding distance), so the mean value of that correction factor of 3.2 has been applied. Since the skidding to the forest road is carried out from the areas which are located on both sides of the road, we use the value 0.8 in the mathematical formula for the calculation of the optimum openness of the forest area.

Dietz, Knigge & Löffler (1984) mention that Abegg (1988) differs three systems of forest opening:

1. Opening by forest roads and the system of unbuilt skid trails on the terrain suitable for driving. Some routes of skid trails need to be built.
2. Opening by forest roads and the system of built skid trails. The wood is collected by a tractor winch to the road or a skid trail, and then skidded along the skid trail to a road.
3. Opening by forest roads and a system of rope-way lines. It is used for extremely steep and inaccessible terrains.

The same author emphasises that on steep and inaccessible terrains the advantage should be given to the second system of opening with the maximum real skidding distance of 500 m in difficult terrain conditions and 300 m in somewhat more favourable conditions of relief features.

Habsburg (1970), Sanktjohanser (1971), Piest (1974), agree that for the needs of forest utilization, depending on terrain and forest stand features, the optimum density of forest road network should be between 17 and 30 m/ha, while for the total forest management, the optimum density is a bit higher.

The aimed openness for our research area, determined regarding the effort to achieve the average aimed real mean skidding distance in the range between 270 to 230 m, is between 30 and 35 m/ha, i.e. approximately 20 to 25 m/ha of forest roads in the Management Unit Lisina and about 21 to 26 m/ha of forest roads in the Management Unit Veprinačke šume.

The average aimed geometrical mean skidding distance represents the quotient of the average aimed real mean skidding distance and factors of skidding wood assortment for the opened area which is 1.58. And finally, for the average aimed real mean skidding distance the value of 250 m has been chosen and its calculated geometrical equivalent is 158 m.

2.1.4. The analysis of the relative openness for the calculated average aimed real mean skidding distance – *Raščlamba relativne otvorenosti za izračunatu prosječnu ciljanu stvarnu srednju udaljenost privlačenja*

The relative openness of the researched area had to be calculated for the calculated optimum real mean skidding distance. The size of the relative openness is a good indicator of the efficiency of the forest transport network, since both numerical and graphical summaries show open and unopened areas. The relative openness is calculated according to the following mathematical expression:

$$O_R = \frac{P_O}{P_U} \cdot 100$$

Legend:

O_R – relative openness (%), P_O – open area for the calculated average aimed real mean skidding distance (ha), P_U – total area of the opened area (ha).

The procedure of the relative openness consists of laying the bordered areas around forest and public roads, which can be used for wood skidding. The distance of fringe parts of bordered areas from the road is the size of the double aimed average geometrical mean skidding distance. The total open surface is obtained by summing the surfaces of bordered areas laid around all roads, whereby the average bordered areas of two or more forest roads are taken into account only once, by the order of analysis which agrees with the order of building forest roads.

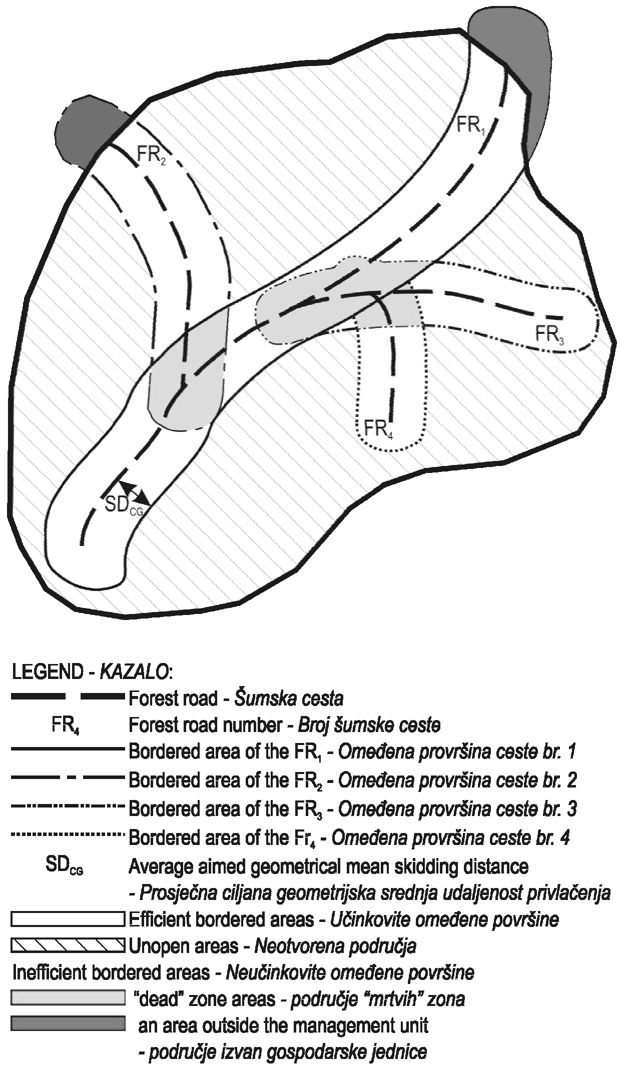

Figure 3 The scheme of the bordered areas method

Slika 3. *Shematski prikaz metode omeđenih površina*

The relative openness is analysed by the use of a computer on topical maps of the research area in digital form as a basis, for which the programme ArcGIS is used.

In evaluating and commenting the relative openness, the following evaluation system, which we have developed ourselves, have been used: till 55 % – insufficient openness (1), from 55 to 65 % – poor openness (2), from 65 to 75 % – hardly good openness (3), from 75 to 85 % – very good openness (4) and over 85 % – excellent openness (5).

All variants of the chosen average aimed real mean skidding distance values of the relative openness are above 70 % in the Management Unit Veprinačke šume and above 80 % in the Management Unit Lisina. These values of the relative openness have been given the adequate evaluations, so the analysis results have shown hardly good (3) or very good (4) relative openness of the researched area.

Together with the relative openness, in the analysis of the forest road efficiency, we have used the efficiency coefficient of the forest road network. It represents the relation of the sums of surface areas, which are open with two or more forest (or public) roads (the sum of the profile of bordered areas laid around all the roads) and the total surface of the bordered areas and in nature it expresses the quality of laying-out forest roads and their distribution in space, i.e. it shows the percentage of bordered areas, which open the unopened surface of the open area. The formula for calculation of the efficiency coefficient of the forest road network is:

$$k_U = \left(1 - \frac{P_N}{P_O}\right) \cdot 100$$

Legend:

k_U – efficiency coefficient of the forest road network, P_N – surface of the inefficiency of bordered areas, P_O – open area for the chosen average aimed real mean skidding distance.

The part of the forest area, which is opened with two or more roads, i.e. the place in which there is overlapping of more bordered areas within the borders of the researched Management Unit is called the dead zone. The part of bordered areas outside the surface of the Management Unit that we are opening is also considered the dead zone.

We have analysed the efficiency of forest roads for both Management Units for average aimed real mean skidding distance of 250 m.

In Management Unit Lisina, for the chosen average aimed real mean skidding distance of 250 m, the efficiency coefficients of forest roads are between the minimum 0.00 % (forest road No. 6) till maximum 66.18 % (forest road No. 2), while for the whole designed and built up forest road network, the efficiency coefficient is 38.58 %. The efficiency coefficients in the Management Unit Veprinačke šume for the average aimed real mean skidding distance of 250 m are in the interval of 12.44 % (forest road No. 1) to 85.04 % (forest road No.3). The efficiency coeffi-

Table 3 Relative openness of the Management Unit Lisina and the Management Unit Veprinačke šume for various variants of the chosen geometrical mean skidding distances

Tablica 3. *Relativna otvorenost Gospodarske Jedinice Lisina i Gospodarske Jedinice Veprinačke šume za različite inačice odabrane ciljane geometrijske srednje udaljenosti privlačenja*

	Average aimed geometrical mean skidding distance, m *Prosječna ciljana geometrijska srednja udaljenost. privlačenja, m*					
	145	149	153	158	163	169
Management Unit (M.U.) Lisina – *Gospodarska jedinica (GJ) Lisina*						
Surface of the bordered areas, ha *Ploština omeđenih površina, ha*	1485.09	1511.70	1538.94	1567.07	1596.08	1626.46
Bordered areas within the M.U., ha *Ploština omeđenih površina unutar GJ, ha*	1207.11	1223.54	1239.66	1255.42	1270.92	1286.60
Relative openness, % *Relativna otvorenost, %*	79.18	80.26	81.32	82.35	83.37	84.40
Estimate of the relative openness *Procjena relativne otvorenosti*	4	4	4	4	4	4
Management Unit (M.U.) Veprinačke šume – *Gospodarska jedinica (GJ) Veprinačke šume*						
The surface of the bordered areas, ha *Ploština omeđenih površina, ha*	1656.07	1693.79	1733.02	1773.93	1816.53	1860.43
Bordered areas within the M.U., ha *Ploština omeđenih površina unutar GJ, ha*	1419.87	1446.06	1472.95	1500.55	1528.66	1557.02
Relative openness, % *Relativna otvorenost, %*	72.78	74.12	75.50	76.92	78.36	79.81
Estimate of the relative openness *Procjena relativne otvorenosti*	3	3	3	4	4	4

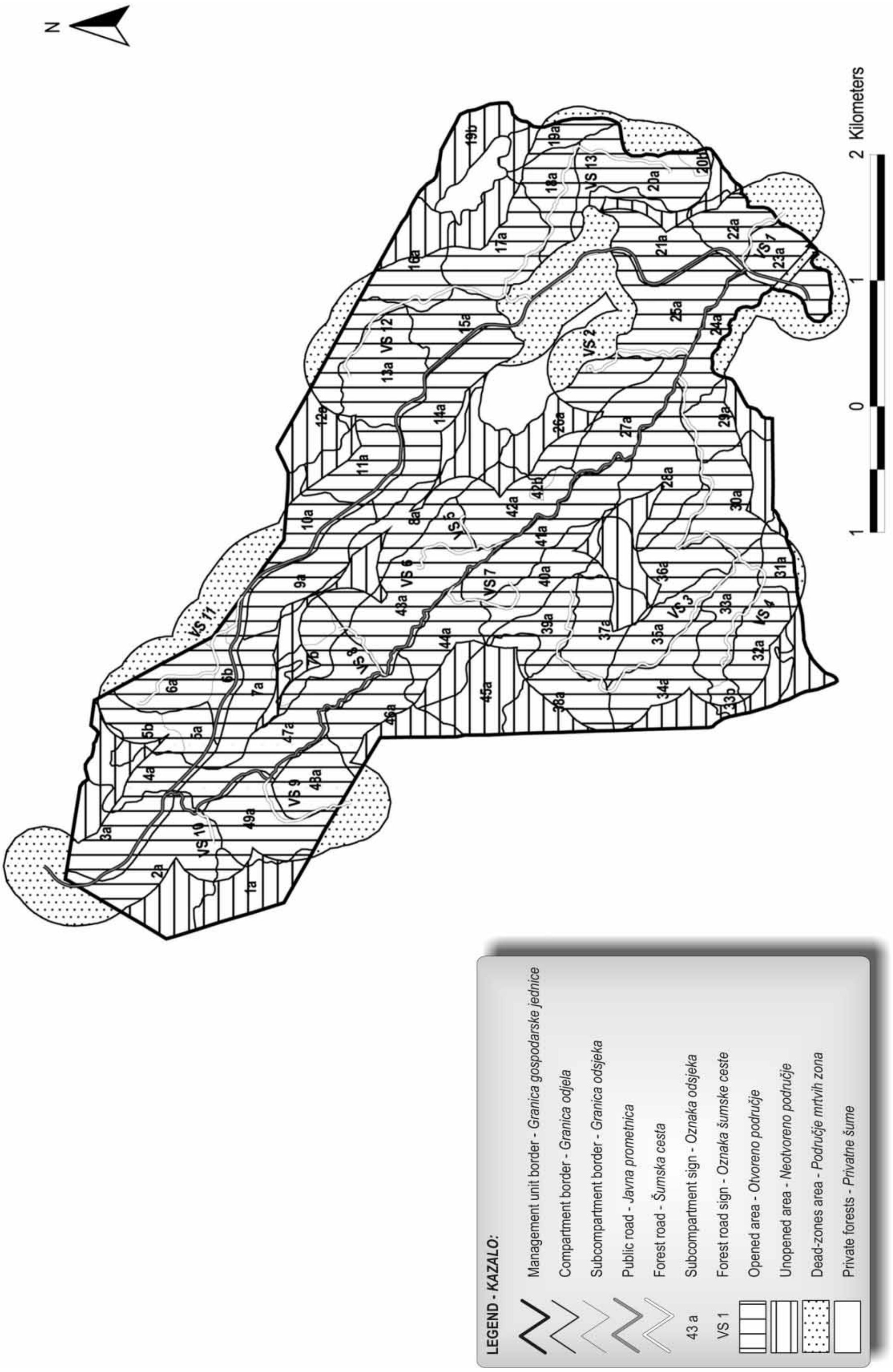

Figure 4 The analysis of relative openness of the M.U. Veprinačke šume (Sd_{CS} = 250 m)

Slika 4. *Raščlamba relativne otvorenosti GJ Veprinačke šume (Sd_{CS} = 250 m)*

Table 4 The results of efficiency analysis of the existing forest roads of the Management Unit Lisina and the Management Unit Veprinačke šume for the average aimed real skidding distance of 250 m

Tablica 4. *Rezultati raščlambe učinkovitosti postojećih šumskih cesta Gospodarske Jedinice Lisina i Gospodarske Jedinice Veprinačke šume za prosječnu ciljanu stvarnu srednju udaljenost privlačenja od 250 m*

Number and sign of FR *Broj i oznaka ŠC-e*	Surface of bordered areas, ha *Ploština omeđenih površina, ha*			Efficiency coefficient, % *Koeficijent učinkovitosti, %*	Number and sign of FR *Broj i oznaka ŠC-e*	Surface of bordered areas, ha *Ploština omeđenih površina, ha*			Efficiency coefficient, % *Koeficijent učinkovitosti, %*
	Efficient areas *Učinkovite površine*	Inefficient areas *Neučinkovite površine*				Efficient areas *Učinkovite površine*	Inefficient areas *Neučinkovite površine*		
		Outside M.U. *Izvan GJ*	Dead zones *Mrtve zone*				Outside M.U. *Izvan GJ*	Dead zones *Mrtve zone*	
	Sd_{CS}, m	Sd_{CS}, m	Sd_{CS}, m			Sd_{CS}, m	Sd_{CS}, m	Sd_{CS}, m	
M.U. Lisina – GJ Lisina					M.U. Veprinačke šume – GJ Veprinačke šume				
1	91.99	17.09	41.18	61.22	1	8.88	23.38	39.08	12.44
2	120.76	2.66	59.06	66.18	2	23.93	24.04	39.12	27.47
3.1	75.57	13.73	70.61	47.26	3	263.94	1.05	45.39	85.04
3.2	12.61	17.57	53.84	15.01	4	42.39	2.65	56.64	41.69
4	45.83	0.00	44.79	50.57	5	10.48	0.00	39.21	21.09
5	40.49	4.48	59.10	38.91	6	24.77	0.00	58.30	29.82
6	0.00	0.00	68.05	0.00	7	16.47	0.00	62.03	20.98
7	5.02	29.57	33.35	7.39	8	24.05	0.00	42.10	36.36
8	70.67	70.22	14.53	45.47	9	29.07	21.70	38.30	32.64
B	41.46	37.19	164.60	17.05	10	13.31	0.00	35.68	27.16
Beljač	31.16	41.33	20.26	33.60	11	32.34	36.01	50.19	27.28
34 b	70.02	0.24	41.71	62.54	12	78.34	36.79	34.67	52.30
Šija	21.72	0.00	93.68	18.82	13	95.92	41.79	29.55	57.35
?	627.31	234.07	764.74	38.58	?	663.90	187.41	570.25	46.70

Note: The order of the forest road analysis in the Management Unit Lisina corresponds to the order of entering of forest roads in the table, while the order of forest roads in the Management Unit Veprinačke šume is as follows: forest road 1, 2, 3, 4, 6, 5, 7, 8, 9, 10, 11, 12, 13.

cient of the whole forest road network in the Management Unit is 46.70 % which is by 8.12 % more than in the Management Unit Lisina.

The total efficiency coefficient of the forest road network of the researched area is in inverse proportion to the average aimed real mean skidding distance. Consequently it is necessary to carry out the politics of long-term, planned forest opening with clearly defined aims we want to achieve and results we intend to obtain.

2.1.5. Defining and marking of unopened areas – *Definiranje i obilježba neotvorenih površina*

Unopened areas for certain average aimed real mean skidding distance, i.e. those areas which stayed outside the bordered areas in the analysis of relative openness, represent potential places of routes of future forest roads. These unopened areas have to be separated since in the further procedure of finding optimum routes of future forest roads, all the attention will be focused on these areas.

3. Conclusions – *Zaključci*

In the analysis of the existing primary forest road infrastructure we have used the usual methods and procedures but also our own methods and evaluation systems.

The method of bordered areas in combination with the relative openness for which the system of quality evaluation was made, represents an extremely efficient means for the analysis of the existing forest road network, separating unopened areas and their further opening. Together with the data on the forest road quantity, it gives us the information on the quality of their spatial distribution.

The method of minimum total costs of wood skidding as a procedure of finding the optimum openness of certain forest area is subjected to great flexibility and it will remain so till the moment when all entry components of the calculation can be precisely defined and all relevant factors are included in the mathematical expression. Till then, taking into account all special features of the area for which we use the computer model, it is better to use the size of the aimed mean skidding distance as a measure we want to achieve.

For the researched area, the average aimed real mean skidding distance of 250 m has been determined, which together with the factor of wood assortment skidding of 1.58 gives the average aimed geometrical mean skidding distance of 158 m. The width of bordered areas on each side of a forest road in nature (it is presumed that skidding is carried out from both sides of the forest road) is double the average aimed real mean skidding distance.

Inventorying the primary forest road infrastructure of the researched area (for both Management Units) 39.19 km forest and 31.62 km public roads have been determined, which influence the decrease of the mean skidding distance, i.e. the total of 70.81 km of roads. The openness of the Management Unit Lisina is 23.72 km/1000 ha and of the Management Unit Veprinačke šume 17.76 km/1000 ha. The average existing real mean skidding distance of the Management Unit Lisina is 341 m and of the Management Unit Veprinačke šume 344 m. The relative openness of the Management Unit Lisina is 82.35 %, which is estimated as a very good openness (4) and the forest road network efficiency is 38.58 %. The calculated relative openness of the Management Unit Veprinačke šume is 76.92 % (very good openness – 4), while the forest road network efficiency is 46.70 %. Upon observing both researched Management Units as a whole area, we have obtained the relative openness of 81.04 % (very good – 4) and the forest road network efficiency coefficient of 42.37 %.

The results of the analysis of the existing forest road network have shown that it is necessary to carry on with the opening of unopened areas.

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Sažetak

Raščlamba postojeće mreže primarne šumske prometne infrastrukture

Aktualna problematika otvaranja neotvorenih, nedovoljno otvorenih ili nekvalitetno otvorenih šuma u Hrvatskoj s jedne strane te nepostojanje naputka za provedbu postupka otvaranja, zahtjevnost i skupoća posla te teško otklonjive možebitne pogreške s druge strane, potaknule su nas na izradbu protokola otvaranja šuma. Taj je protokol, metodološka studija, zapravo naputak po kojem bi trebalo izrađivati studije otvaranja određenih šumskih područja. Njegova fleksibilnost omogućuje mu široku primjenu i oblikovanje prema osobnim potrebama i značajkama područja na kojem se primjenjuje, dok istodobno definira globalne smjernice rada, preporučljive tehnologije, tehnike, metode i matematičke algoritme.

U prethodnim radovima definirali smo faze kreiranja sveobuhvatno optimizirane mreže ŠC-a te smo za njih izradili dijagrame tokova podataka kako bi ih u budućnosti mogli iskoristiti kao podloge za što veće automatiziranje postupka otvaranja šuma uz interaktivni princip komunikacije na relaciji korisnik – računalo. To su sljedeće faze rada: 0 – Definiranje osnovne funkcije šuma sastojinskoga oblika i načina gospodarenja te dizajniranje računalnih baza podataka, 1 – Raščlamba postojeće mreže primarne šumske prometne infrastrukture, 2 – Određivanje potencijalnih trasa budućih ŠC-a, 3 – Raščlamba odabranih mogućih lokacija budućih ŠC-a i postizanje ciljane otvorenosti, 4 – Optimiziranje mreže odabranih ŠC-a glede visinskoga razvijanja trase i 5 – Ispitivanje opstojnosti modela na terenu te izradba projektne dokumentacije.

Prva se faza rada – ***Raščlamba postojeće mreže primarne šumske prometne infrastrukture****, sastoji od niza operacija i postupaka kojima je osnovna zadaća utvrditi kakvoću, kolikoću i možebitne nedostatke postojeće mreže cesta. Ovisno o polučenim rezultatima raščlambe, usmjerit će se daljnji tijek optimiziranja. Slijedom propisanih operacija i postupaka treba odrediti: prosječnu postojeću stvarnu srednju udaljenost privlačenja, postojeće troškove privlačenja drva, ciljanu otvorenost i ciljanu stvarnu srednju udaljenost privlačenja, relativnu otvorenost za izračunanu prosječnu ciljanu stvarnu srednju udaljenost privlačenja, učinkovitost pojedine šumske ceste i cestovne mreže u cjelini, te definirati neotvorene površine. U članku je dan detaljan opis svakoga koraka ove faze rada koja je prikazana na primjeru dviju planinskih gospodarskih jedinica u sastavu Šumarije Opatija, Uprava šuma Podružnice Buzet.*

Definirali smo ove sastavnice prve faze optimiziranja:

1.1. Određivanje prosječne postojeće stvarne srednje udaljenosti privlačenja:
- *Određivanje težišta svakoga odsjeka,*
- *Utvrđivanje postojeće geometrijske srednje udaljenosti privlačenja pojedinoga odsjeka,*
- *Definiranje veličine čimbenika privlačenja drvnih sortimenata za otvarano područje,*
- *Izračun postojeće stvarne srednje udaljenosti privlačenja pojedinoga odsjeka,*
- *Iznalaženje prosječne postojeće stvarne srednje udaljenosti privlačenja za čitavo otvarano područje,*

1.2. Određivanje postojećih troškova privlačenja drva:
- *Izračun proizvodnosti jediničnih troškova privlačenja pojedinoga odsjeka,*
- *Izračun ukupnih troškova privlačenja pojedinoga odsjeka i cjelokupnih troškova privlačenja gospodarske jedinice,*

1.3. Izračun prosječne ciljane geometrijske srednje udaljenosti privlačenja:
- *Definiranje prosječne ciljane stvarne srednje udaljenosti privlačenja,*
- *Definiranje veličine čimbenika privlačenja drvnih sortimenata za otvarano područje,*
- *Izračun prosječne ciljane geometrijske srednje udaljenosti privlačenja,*

1.4. Raščlamba relativne otvorenosti za izračunanu prosječnu ciljanu stvarnu srednju udaljenost privlačenja:
- *Polaganje omeđenih površina tzv. "buffera" oko mreže cesta (šumskih i javnih),*
- *Izračun relativne otvorenosti za izračunanu prosječnu ciljanu stvarnu srednju udaljenost privlačenja,*
- *Utvrđivanje neučinkovitih površina (tzv. "mrtvih zona"),*
- *Izračun koeficijenta učinkovitosti mreže ŠC-a,*
- *Ocjena i komentar relativne otvorenosti istraživanoga područja te koeficijenta učinkovitosti mreže ŠC-a,*

1.5. Definiranje i izlučivanje neotvorenih površina.

Pri raščlambi postojeće mreže primarne šumske prometne infrastrukture koristili smo se uobičajenim metodama i postupcima (određivanje prosječne postojeće stvarne srednje udaljenosti privlačenja težišnom metodom, utvrđivanje postojećih troškove privlačenja drva matematičkim algoritmima), ali i vlastito kreiranim metodama i sustavima procjene (izračun ciljane otvorenost i ciljane stvarne srednje udaljenosti privlačenja, određivanje rela-

tivne otvorenosti za izračunanu prosječnu ciljanu stvarnu srednju udaljenost privlačenja, pronalaženje koeficijenta učinkovitosti pojedine šumske ceste i cestovne mreže u cjelini).

Metoda omeđenih površina u kombinaciji s relativnom otvorenošću za koju je izrađen sustav procjene kakvoće izuzetno je učinkovito sredstvo pri raščlambi postojeće mreže šumskih cesta, izlučivanju neotvorenih područja i njihovu daljnjem otvaranju. Ona nam, uz podatak o količini šumskih cesta, daje podatak i o kakvoći njihova prostornoga (položajnoga) razmještaja.

Metoda minimalnih cjelokupnih troškova pridobivanja drva kao postupak pronalaženja optimalne otvorenosti određenoga šumskoga područja podložna je velikoj fleksibilnosti, i tako će ostati sve do trenutka kad se budu točno mogle definirati ulazne sastavnice izračuna te matematičkim izrazom obuhvatili svi relevantni čimbenici. Do tada je, uzimajući u obzir sve posebnosti područja za koje primjenjujemo računalni model, kao mjeru koju težimo postići bolje uporabljivati veličinu ciljane srednje udaljenosti privlačenja.

Za istraživano područje utvrđena je prosječna ciljana stvarna srednja udaljenost privlačenja od 250 m, što uz čimbenik privlačenja drvnih sortimenata 1,58 daje prosječnu ciljanu geometrijsku srednju udaljenost privlačenja 158 m. Širina omeđenih površina na svaku stranu ŠC-a u prirodi (pretpostavlja se da se privlačenje obavlja s obje strane ŠC-a) iznosi dvostruku vrijednost prosječne ciljane stvarne srednje udaljenosti privlačenja.

Inventarizacijom primarne šumske prometne infrastrukture istraživanoga područja (za obje gospodarske jedinice) utvrđeno je 39183,47 m šumskih i 31615,65 m javnih cesta koje utječu na smanjenje srednje udaljenosti privlačenja odnosno ukupno 70799,12 m cesta. Otvorenost GJ Lisina iznosi 23,72 m/ha, a GJ Veprinačke šume 17,76 m/ha. Prosječna postojeća stvarna srednja udaljenost privlačenja GJ Lisina je 341,07 m, a GJ Veprinačke šume 343,98 m. Relativna otvorenost GJ Lisina iznosi 82,35 %, što je ocijenjeno kao vrlo dobra otvorenost (4), a učinkovitost mreže ŠC-a je 38,58 %. Za GJ Veprinačke šume izračunana je relativna otvorenost 76,92 % (vrlo dobra otvorenost – 4), dok učinkovitost mreže ŠC-a iznosi 46,70 %. Kad smo obje istraživane gospodarske jedinice promatrali kao cjelovito područje, dobili smo relativnu otvorenost 81,04 % (vrlo dobar – 4) i koeficijent učinkovitosti mreže ŠC-a 42,37 %.

Rezultati raščlambe postojeće mreže šumskih cesta pokazali su da je potrebno provesti daljnje otvaranje neotvorenih područja.

Ključne riječi: *šumske ceste, mreža šumskih cesta, otvorenost, srednja udaljenost privlačenja, troškovi privlačenja, transport drva*

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