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OPTIMIZATION OF THE SKID ROADS NETWORK

OPTIMIZACIJA MREŽE TRAKTORSKIH PUTEVA

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Abstract

Optimization of the skid roads network is a critical aspect of planning forest harvesting operations, as timber transport (including extraction and long-distance road transport) represents the most expensive stage of timber production. This task entails a well-structured spatial distribution of skid roads, essential for timber extraction using tractors, skidders, forwarders, or animal assistance. A high-quality spatial distribution of skid roads enables efficient timber utilization. The primary indicator of the spatial distribution of skid roads is relative forest accessibility, with optimization efforts aimed at increasing this indicator within compartments above 90%. Achieving such optimization level relies on employing spatial and statistical analysis techniques on vector and raster data concerning terrain stand conditions, and the current state of secondary forest road infrastructure, facilitated by GIS tools. These methods allow for precise evaluation and planning enhancing both efficiency and cost-effectiveness in timber transport. The research results show a significant increase in the total length of tractor roads, from 3,311.15 m to 4,152.15 m, with a corresponding density increase from 84.55 to 106.33 m/ha based on forest compartment area of 39.16.ha. The average skidding distance ranges from 95 m to 111 m for the existing and upgraded skid road networks. The relative forest accessibility is 81% for the existing skid roads network, while for the upgraded skid roads network is around 97%. The primary goal of the research is achieved.

Key words: extraction, GIS, planning, skid roads,

1. INTRODUCTION / UVOD

The forest traffic infrastructure network consists of primary and secondary components, the primary network comprising forest roads, and the secondary one including skid roads. The skid roads network supports ground-based timber extraction, facilitating the timber movement from stump to landing. Bosnia and Herzegovina predominantly employs harvesting methods where trees are felled and processed at the stump using chainsaws, followed by timber extraction primarily using skidders. This skidding process results in so-called "skidding distance," as noted by Marčeta et al. (2014).

Skid roads are mostly temporary, created by clearing paths through the forest, potentially removing stumps, and with tracks compacted by repeated skidders' movement (Pentek et al., 2014). A critical design element in skid roads is the longitudinal slope, as it directly influences skidder productivity and impacts soil erosion and compaction along the road surface (Lotfalian et al., 2012; Akbarimher et al., 2012). Current guidelines advise that the maximum longitudinal slope for skid roads should generally not exceed 20% (Najafi et al., 2010), though earlier standards allow up to 30% (Bojanin, 1983; Jeličić, 1977). If skid roads are to be converted into permanent forest roads, slopes should ideally remain under 12% (Jeličić, 1971). This infrastructure design approach helps balance productivity with environmental considerations like soil protection.

Forest accessibility indicators include the density of the forest traffic infrastructure, average extraction distance, relative forest accessibility, and the efficiency coefficient of the infrastructure network. The density of this infrastructure is defined as the ratio between the total length of skid roads and the overall forest area (Equation 1). Current density levels for skid roads in the Republic of Srpska (RS) range from 40 to 200 m/ha, as observed by Danilović and Ljubojević (2013). The optimal skid road density for high forests with natural regeneration should range between 100 and 200 m/ha, according to Jeličić (1983) and further supported by Danilović and Ljubojević (2013). These indicators serve as critical tools for monitoring and enhancing the efficiency of the forest traffic network, enabling data-driven improvements in forest accessibility and resource management.

$$\boldsymbol{O} = \frac{\mathbf{D}}{\mathbf{P}} \qquad (1)$$

Where is:
O – density of skid roads (m/ha),
D – length of skid roads in the analyzed forest area (m),
P – area of the analyzed forest area (ha).

These variables are used in the equation for calculating skid road density, as documented by Sokolović and Bajrić (2013), Sokolović et al. (2013), and Petković and Potočnik (2018).

The second indicator of forest accessibility, average extraction distance, significantly influences the productivity and costs associated with timber transport. Since the skidders are predominantly used for timber extraction, understanding this distance is essential for optimizing efficiency. The calculation for skidding distance in the context of a skid road network is provided by Equation 2, which integrates variables relevant to the specific layout and operational characteristics of skid roads. The average skidding distance is the weighted mean, where the weight is the area from which timber is skidded along the skid roads belonging to a specific forest landing (gravitational zone). By minimizing this distance, the extraction process can reduce transport costs and improve productivity, as longer distances typically demand more time and fuel, directly impacting overall expenses.

$$\boldsymbol{S_d} = \frac{\boldsymbol{\Sigma} \mathbf{Liw} * \boldsymbol{V_i}}{\boldsymbol{\Sigma V i}} \qquad (2)$$

Where:

Sd - the average skidding distance of timber by skid roads, measured in meters (m).

Liw - the total length of skid roads, measured in meters (m).

Vi - the volume of skidded roundwood, measured in cubic meters (m^3) (Ljubojević et al., 2018).

Relative forest accessibility and the efficiency coefficient of the skid roads network are key indicators of quality in forest accessibility, with particular emphasis on relative forest accessibility. This term, introduced by Backmund (1966), quantifies the proportion of forest that is accessible compared to the total forest area and is calculated using Equation 3. Relative forest accessibility is a crucial metric as it provides insight into how well the infrastructure serves the forest area, ensuring efficient timber skidding with minimized environmental impacts. A higher relative accessibility percentage indicates a well-developed skid road network that supports cost-effective and environmentally responsible forest operations.

$$O_R = \frac{P_O}{P_U} * 100 \quad (3)$$

Where is:
O_R - relative forest accessibility (%),
P_O - area around skid roads (ha),
P_U - area of compartment (ha).

This indicator provides insight into the effectiveness of the skid road network in making the forest area accessible for timber extraction (Pentek et al., 2005; Sokolović and Bajrić, 2013; Sokolović et al., 2013; Petković and Potočnik, 2018).

According to Sokolović et al. (2013), relative forest accessibility is the ratio between the number of marked trees within the area around skid roads and the total number of marked trees. This approach provides a specific measure of how effectively skid roads serve the area intended for timber extraction, focusing on the proportion of accessible, marked trees. By assessing this ratio, forest management can better understand and improve the spatial reach of skid roads to support more efficient harvesting operations.

$$O_{RN} = \frac{N_O}{N_{OD}} * 100 \quad (4)$$

Where is:
O_{RN} – relative forest accessibility based on the number of marked trees,
N_O - number of marked trees in the area around skid roads,
N_{OD} - total number of marked trees.

The accessible forest area adjacent to forest traffic infrastructure is defined by the width around roads and skid trails, which varies based on terrain, slope, and extraction direction. Hentschel (1996) explains that factors such as winching distance, terrain slope, and average log length are critical in optimizing both theforest road network and the skid road network. The spacing between skid roads should not exceed twice the winching distance plus the average log length on each side of the skid roads (Jeličić, 1977), which implies a recommended skid road spacing of approximately 130 meters (Danilović & Ljubojević, 2013; Jeličić, 1977; Sokolović et al., 2013). The winching distances are typically 10, 20, or 30 meters, resulting in an effective area width around skid roads (or road spacing) of 20, 40, and 60 meters, respectively (JPŠ, 2002). According to Pentek et al. (2008), winching distance can be 30, 40, 50, and 60 m, and the width of the area around skid roads is 60, 80, 100, and 120 m, respectively and these distances were reduced based on the slope of the terrain.

Relative forest accessibility is categorized as follows: up to 60% is considered insufficient; 60-70% is poor; 70-80% is marginally good; 80-90% is very good; and above 90% is deemed excellent (Pentek et al., 2005). The relative forest accessibility ranges from 85 to 90 % in conditions of high forests with natural regeneration (Bunić, 2020; Emrulović, 2020).

The efficiency coefficient of the forest road network measures the ratio of ineffective, multiple-access areas to total single-access areas within the forest road network. This coefficient provides insight into how effectively the infrastructure is planned and utilized, aiming to reduce redundancies and improve accessibility across the forest. Equation 5 can be used to calculate this coefficient, as detailed by Pentek et al. (2005), Sokolović and Bajrić (2013), and Petković and Potočnik (2018). A higher efficiency coefficient indicates a well-designed road network with minimized overlap, allowing for cost-effective and environmentally responsible forest operations.

$$k_U = \left(1 - \frac{P_N}{P_U}\right) * 100 \quad (5)$$

Where is:

k_U - efficiency coefficient of the skid road network (%),

P_N - multiple accessible areas in the forest area which is accessible (ha),

P_O - single accessible areas within the accessible forest area for the chosen double winching distance (ha) (Pentek et al., 2005; Sokolović & Bajrić, 2013; Sokolović et al., 2013; Petković & Potočnik, 2018).

This efficiency coefficient (k_U) provides a measure of how effectively the skid roads network covers the forest area, with the goal of minimizing overlap across the entire compartment (Pentek et al., 2005; Petković & Potočnik, 2018; Sokolović & Bajrić, 2013; Sokolović et al., 2013). It should be as high as possible since a lower coefficient means that skid roads are multiple overlapping and crossing.

The optimization of the secondary forest traffic infrastructure network involves the strategic spatial distribution of skid roads to enhance forest accessibility while minimizing damage from winching to surrounding trees, soil, equipment, and roundwood assortments, as well as winching costs and occupational injuries and diseases. Effective spatial arrangement in skid roads is crucial for increasing accessibility within forest compartments, reducing extraction costs and environmental impact.

The primary goal of this optimization is to improve relative forest accessibility to an excellent level. It means that more than 90 % of the forest compartment is accessible for double winching distance around skid roads. This level of accessibility ensures more efficient timber extraction, conserves forest resources by reducing soil compaction and tree damage, and supports sustainable forest management practices (Pentek et al., 2005; Sokolović and Bajrić, 2013).

The primary goal of the research can be achieved through the following stages:

- The analysis of forest accessibility based on the existing skid roads network,
- The new skid roads designed into insufficiently accessible areas of compartments and
- The analysis of forest accessibility based on upgraded skid roads network.

The assumption is that the density of existing skid roads is less than 75 m/ha, and the relative forest accessibility for existing skid roads network is less than 70 %, or rather, its rating is “poor”.

2. MATERIAL AND METHODS / MATERIJAL I METOD RADA

2.1 Research area / Područje istraživanja

The research was conducted in forest compartment 65 (Figure 1), within the Forest Management Unit (FMU) “Čemernica,” part of the Forest Management Area (FMA) “Čemernica” in the municipality of Kneževo. This FMU is managed by the Forest Administration (FA) “Čemernica,” under the Public Forest Enterprise (PFE) “Forests of the Republic of Srpska.” Kneževo is centrally located in Bosnia and Herzegovina and experiences a mountainous climate.

The area of forest compartment 65 is 39.16 ha, classified as high forest with natural regeneration of beech and fir, with spruce among primarily deep limestone soils. Beech, fir, and spruce dominate, while other species appear in minor quantities. Elevations in this area range from 984 to 1,149 m, with an average tree diameter of 30 cm, and timber stock is approximately 309.15 m³/ha. The annual increment is 9.25 m³/ha, and the cutting intensity is 18% of timber stock, a roundwood volume of 2,206.93 m³ based on marked trees (IRPC, 2018).

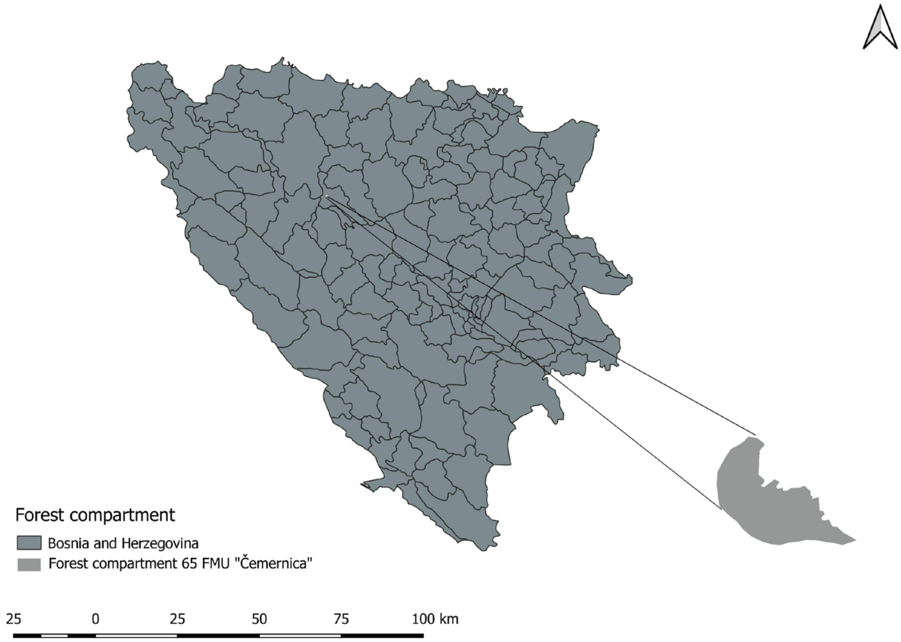

Figure 1. Location of research area in the B&H / **Slika 1**. Položaj područja istraživanja u B&H

2.2 Research methods / Metod istraživanja

The data analysis for optimizing forest traffic infrastructure in the study was performed using QGIS, utilizing both spatial and statistical analysis tools. Skid roads were mapped with a GARMIN GPS device and then imported into QGIS, where their lengths were obtained using the length function in to attribute table.

The length of skid roads is necessary to determine skid road density by Equation 1. This information, combined with the volume of roundwood and the area from which timber is skidded along the skid roads belonging to a specific forest landing (gravitational zone), was used to calculate the average skidding distance (Equation 2). The gravitational zones were defined based on the assignment of marked trees to the nearest skid roads using the Distance to the closest hub Vector analysis tool.

Relative forest accessibility, a key indicator of skid road distribution efficiency, was computed using Equations 3 and 4. For spatial analysis, the accessible forest area around skid roads was determined with a 100-meter buffer width, supported by prior research findings and field experience. The winching distance on each side of skid roads is 50 m. This distance should be reduced from the view of the average slope of terrain in the research area. The slope of the terrain of forest compartment 65 is obtained using QGIS Raster Analysis tool Slope. In addition, the positions of marked trees in forest compartment 65 were used for the relative forest accessibility determination. Each marked tree is assigned to the nearest skid road using the Distance to the closest hub Vector analysis tool. Using QGIS's Vector Geoprocessing Buffer tool with the “Dissolved” option enabled, accessible areas were mapped, while those outside this buffer were identified as insufficiently accessible. These are the basic indicators of forest accessibility (Figure 3).

To address these inaccessible zones, new skid roads were designed following contour lines with 5 m intervals, on the digital terrain model

(DTM), created using QGIS's Raster tool (Extraction Contour). Zero lines were set up along contour lines in these areas to ensure equal segment lengths between contours, all under a controlled longitudinal slope. This slope was maintained at a maximum of 12 %, as specified for sustainable skid road design. The zero lines were set up using QGIS's Advanced Digitizing Panel tool, where in box d is the entered length between contours (42 m) for a maximum of 12 % of the longitudinal slope of the skid road (Figures 2 and 3).

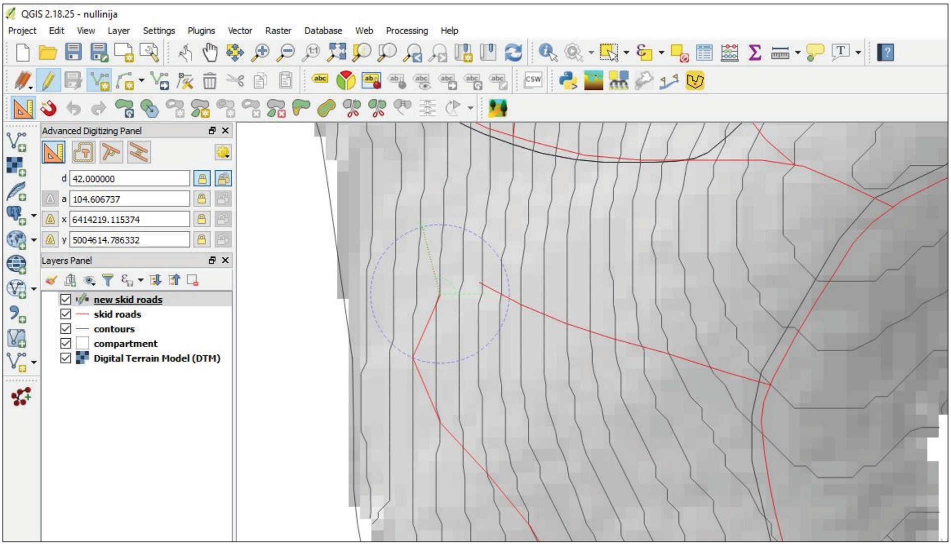

Figure 2. QGIS Advanced Digitizing Panel / **Slika 2**. QGIS Advanced Digitizing Panel

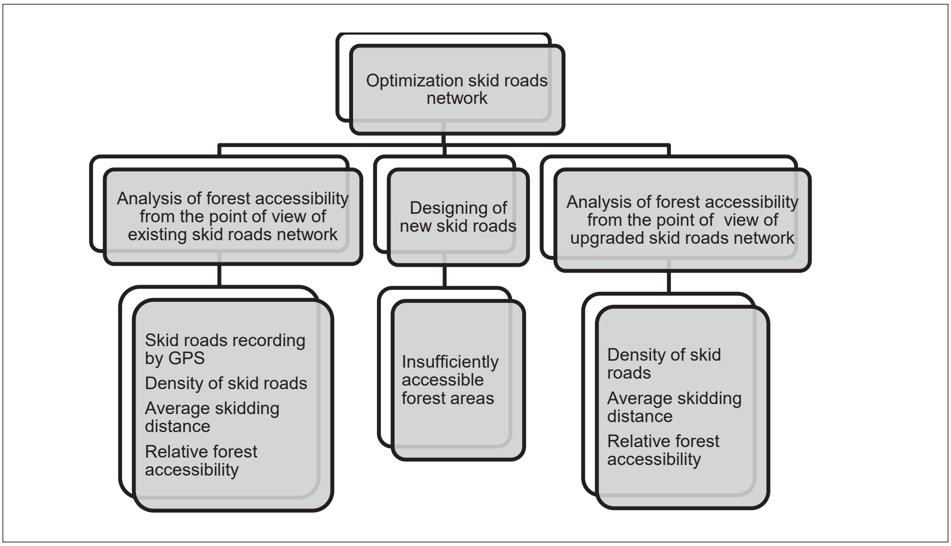

Figure 3. Research programme / **Slika 3**. Program istraživanja

Following road placement, the network's quality was re-evaluated to ensure that the relative forest accessibility exceeded 90%, supporting operational efficiency and sustainable forest management objectives (Figure 3).

3. RESULTS AND DISCUSSION / REZULTATI I DISKUSIJA

In forest compartment 65, which covers an area of 39.16 ha, the total length of existing skid roads (Figure 4) is 3,311.15 m (Table 1), resulting in a current skid road density of 84.55 m/ha.

$$O = \frac{\mathrm{D}}{\mathrm{P}} = \frac{3{,}311.15}{39.16} = 84.55\,\frac{m}{ha}$$

Three new or planned skid roads totaling 841 m (Figure 5) were designed in previously insufficiently accessible areas to improve accessibility, bringing the upgraded skid road network length to 4,152.15 meters. This enhancement raises the skid road density to 106.03 m/ha - an increase of 21.48 m/ha from the existing density, aligning the network with optimal management standards for high forests.

$$O = \frac{\mathrm{D}}{\mathrm{P}} = \frac{4{,}152.15}{39.16} = 106.03\,\frac{m}{ha}$$

For comparison, Emrulović (2020) reported actual skid road densities of 145.82 m/ha and 169.3 m/ha in similar forest stand conditions, while Bunić (2020) estimated that the optimal skid road density should range between 130 and 140 m/ha.

The maximum allowable density of skid roads, considering the conditions for timber harvesting, is as follows:

- Karst terrain: 180 m/ha,
- Hilly terrain: 150 m/ha,
- Alpine terrain: 130 m/ha (Pravilnik o gozdnih prometnicah, 2009).

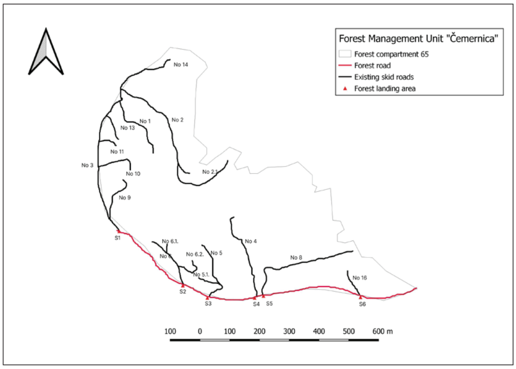

Figure 4. Existing skid roads in forest compartment 65 / **Slika 4**. Postojeći traktorski putevi u odjelu 65

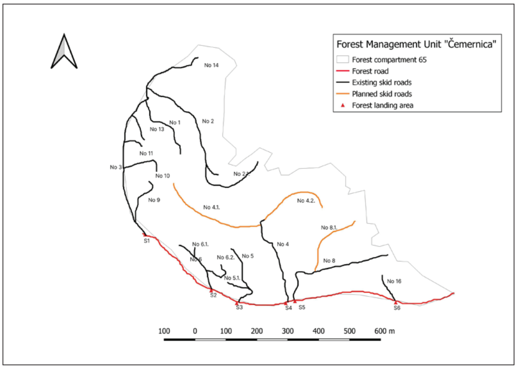

Figure 5. Existing and planned (new) skid roads in forest compartment 65 / **Slika 5**. Postojeći i planirani (novi) traktorski putevi u odjelu 65

The average skidding distance was calculated for the existing and upgraded (existing and planned) skid roads network by Equation 2 based on the length of skid roads, the volume of roundwood, and the area of gravitational zones.

Table 1. Total length of skid roads / **Tabela 1**. Ukupna dužina traktorskih puteva

Skid roads / Traktorski putevi	**Length** / Dužina (m)	**Type of skid road** / Tip traktorskog puta	**Forest landings** / Šumska stovarišta
1.	239.3	Existing	1
2.	413.8	Existing	
2.1.	265.5	Existing	
3.	494.0	Existing	
9.	162.8	Existing	
10.	143.3	Existing	
11.	69.3	Existing	
13.	93.5	Existing	
14.	251.6	Existing	
4.	311.6	Existing	4
4.1.	346.0	New	
4.2.	260.0	New	
5.	233.0	Existing	3
6.	190.2	Existing	2
6.1.	27.25	Existing	
6.2.	240.2	Existing	
8.	77.2	Existing	5
8.1.	235	New	
16.	98.6	Existing	6
Total	4,152.15		

Table 2. Gravitational zones with the volume of roundwood and total length of the existing skid roads / **Tabela 2**. Gravitacione zone sa zapreminom oblog drveta i ukupnom dužinom postojećih traktorskih puteva

Forest landings / Šumska stovarišta	**Length** / Dužina (m)	**Volume of roundwood** / Zapremina krupnog drveta (m^3)	**Area of gravitational zone** / Površina gravitacione zone (ha)
1	2,133.10	594.42	18.88
2	457.65	531.26	3.04
3	233	186.65	2.64
4	311.6	726.93	5.36
5	77.20	100.51	7.12
6	98.60	67,16	2.12
Total	3,311.15	2,206.93	39.16

The average skidding distance for the existing skid roads network is (Table 2) (Figure 6):

$$S_d = \frac{\Sigma \text{Liw} * V_i}{\Sigma Vi}$$

$$= \frac{2{,}133.10 * \frac{594.42}{18.88} + 457.65 * \frac{531.26}{3.04} + 233 * \frac{186.65}{2.64} + 311 * \frac{726.93}{5.36} + 77.20 * \frac{100.51}{7.12} + 98.6 * \frac{67.16}{2.12}}{2206.93\ m^3}$$

$$= \frac{210{,}000.97}{2206.93\ m^3} = 95.16\ m$$

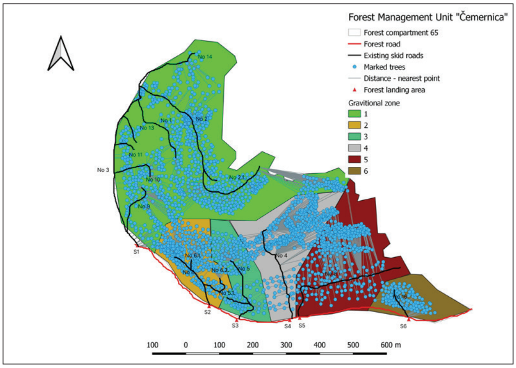

Figure 6. Gravitational zones of roundwood skidding for the existing skid roads / **Slika 6**. Gravitacione zone privlačenja oblog drveta za postojeće traktorske puteve

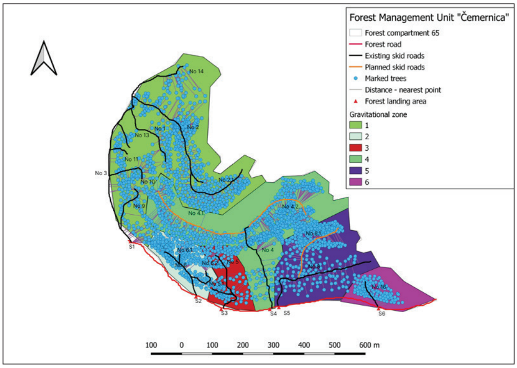

Figure 7. Gravitational zones of roundwood skidding for the existing and planned skid roads / **Slika 7**. Gravitacione zone privlačenja oblog drveta za postojeće i planirane traktorske puteve

The average skidding distance for the upgraded skid roads network is (Table 3) (Figure 7):

Table 3. Gravitational zones with the volume of roundwood and total length of existing and planned skid roads / **Tabela 3**. Gravitacione zone sa zapreminom oblog drveta i ukupnom dužinom postojećih i planiranih traktorskih puteva

Forest landings / Šumska stovarišta	**Length** / Dužina (m)	**Volume of roundwood** / Zapremina krupnog drveta (m^3)	**Area of gravitational zone** / Površina gravitacione zone (ha)
1	2,133.10	635.04	14.72
2	457.65	197.02	2.56
3	233	113,04	2.38
4	917.60	1167,75	10.40
5	312.20	26,92	6.67
6	98.60	67,16	2.43
Total	4,152.15	2,206.93	39.16

$$S_d = \frac{\Sigma \text{Liw} * V_i}{\Sigma Vi}$$

$$= \frac{2133.10 * \frac{635.04}{14.72} + 457.65 * \frac{197.02}{2.56} + 233 * \frac{113.04}{2.38} + 917.60 * \frac{1167.75}{10.40} + 312.20 * \frac{26.92}{6.67} + 98.6 * \frac{67.16}{2.43}}{2206.93\ m^3}$$

$$= \frac{245{,}329.01}{2206.93\ m^3} = 111.16\ m$$

It is higher than existing for 16 m on average.

The slope map of forest compartment 65 shows that the slope ranges from 2.7 % to 62.33 % (Figure 8). The average slope is 32.52 %.Based on it, the winching distance was reduced from 50 m to 47.55 m.

The existing skid roads network in forest compartment 65 provides an accessible forest area of 31.62 ha, yielding relative forest accessibility of 80.74 %, categorized as "very good" (Figure 9).

$$O_R = \frac{P_O}{P_U} * 100 = \frac{31.62}{39.16} * 100 = 80.74\%$$

With the upgraded skid roads, relative forest accessibility improves to 97.32 %, an increase of 16.58 % over the existing network, achieving "excellent" accessibility (Figure 10).

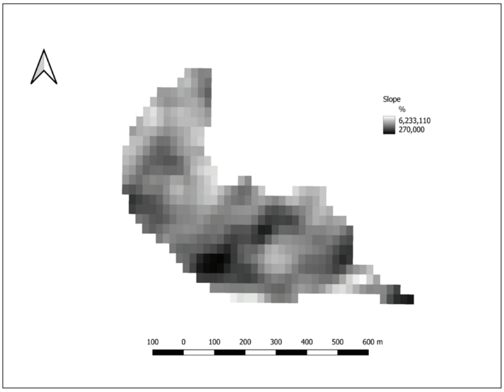

Figure 8. The slope map / **Slika 8**. Karta nagiba

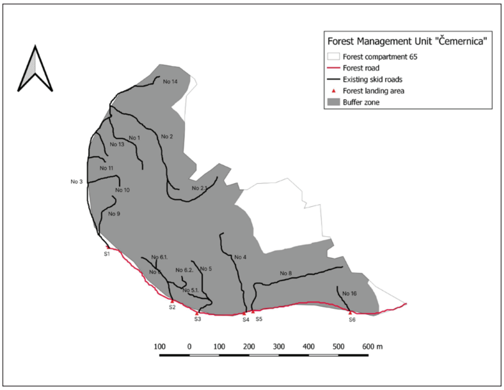

Figure 9. The accessible forest area around the existing skid roads / **Slika 9**. Pristupačna površina šume oko postojećih traktorskih puteva

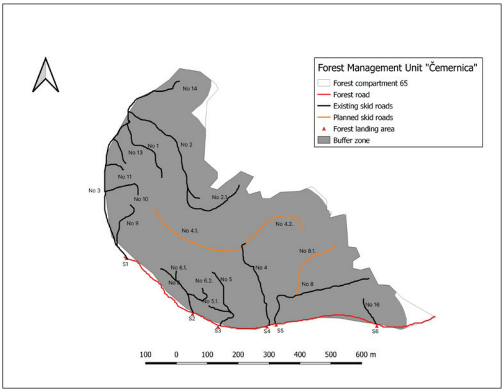

Figure 10. The accessible forest area around existing and new skid roads / **Slika 10**. Pristupačna površina šume oko postojećih i novih traktorskih puteva

$$O_R = \frac{P_O}{P_U} * 100 = \frac{38.11}{39.16} * 100 = 97.32\%$$

The research's primary goal was achieved because relative forest accessibility is above 90%.

For context, Emrulović (2020) reported relative forest accessibility values of 86% for existing networks and 95 % for upgraded networks in similar conditions. Bunić (2020) suggests that optimal relative forest accessibility generally ranges between 85 % and 90 %, further underscoring that the achieved 97.32 % accessibility in forest compartment 65 represents an exceptional improvement in forest traffic infrastructure.

The total number of marked trees in the study area is 2,133, with 1,711 located within accessible forest areas. This results in a relative forest accessibility of 80.21 % for the existing skid road network based on the number of marked trees (Figure 11).

$$O_{RN} = \frac{N_O}{N_{OD}} * 100 = \frac{1{,}711}{2{,}133} * 100 = 80.21\%$$

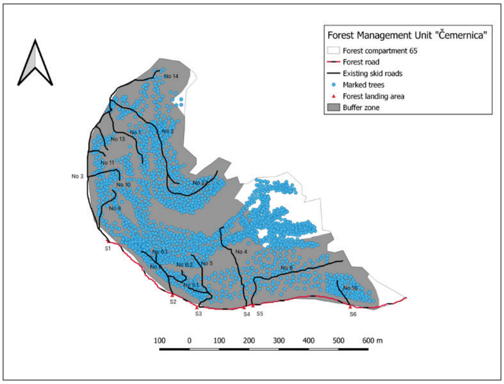

Figure 11. The number of marked trees in the accessible forest areas for existing skid roads / **Slika 11**. Broj doznačenih stabala u pristupačnoj šumskoj površini za postojeću mrežu traktorskih vlaka

For the upgraded skid road network, this indicator improves to 97.23 %, as 2,074 marked trees fall within accessible areas (Figure 12).

$$O_{RN} = \frac{N_O}{N_{OD}} * 100 = \frac{2{,}074}{2{,}133} * 100 = 97.23\%$$

Consequently, the research objective, optimizing accessibility in terms of marked trees, has been achieved. Emrulović (2020) calculated that relative forest accessibility, based on the number of marked trees, ranges from 88 % for existing networks to 97 % for upgraded networks, supporting the findings in this study.

The average skidding distance for the upgraded skid roads network is higher than for the existing 16 m, but it has achieved excellent relative forest accessibility.

The assumption that the density of existing skid roads is less than 75 m/ha has not been confirmed because it is around 85 m/ha. Also, the assumption that the relative forest accessibility for the existing skid roads network is less than 70 % has not been confirmed, because it is 81 % in this case. The relative forest accessibility for the existing skid roads network is very good.

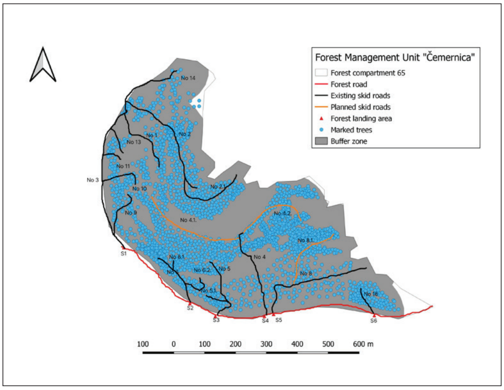

Figure 12. The number of marked trees in accessible forest area for upgraded skid roads network / **Slika 12**. Broj obilježenih stabala u pristupačnoj šumskoj površini za unaprijeđenu mrežu traktorskih vlaka

4. CONCLUSIONS / ZAKLJUČCI

The spatial analysis of terrain, stand characteristics and infrastructure conditions in forest areas by GIS, enhances decision-making in forest management and accessibility planning. The primary task in forest accessibility planning is to select compatible indicators of accessibility that guide optimal design for both forest roads and skid road networks.

Forest Road and Skid Road Indicators: Among indicators, road or skid road density is widely used for determining optimal accessibility. However, relative forest accessibility, especially for skid road networks, is the most critical indicator for optimal spatial distribution. This indicator allows the precise identification of accessibility across different compartments and regions. Economic factors like average skidding distance also play a significant role in optimizing forest accessibility, as both skidding and overall timber transport costs are influenced by extraction distances.

Relative Forest Accessibility Results: The main outcome of relative forest accessibility analysis is not merely the percentage of accessible area but, crucially, the identification of insufficiently accessible zones. For effective planning, these areas are flagged for potential new skid road designs to ensure balanced spatial distribution of them into forest areas. Research findings demonstrate that increasing skid road length and density ultimately raises the percentage of accessible forest area.

The study's primary goal, achieving above 90% relative forest accessibility, was met, establishing excellent accessibility standards that support efficient and sustainable forest management.

The research results have not confirmed the established assumptions. The density of existing skid roads is around 85 m/ha and relative forest accessibility for existing skid roads network is around 81 %.

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Sažetak

Optimizacija otvorenosti šuma traktorskim putevima je ključni aspekt u planiranju šumsko-eksploatacionih aktivnosti, budući da transport drveta (uključujući privlačenje i prevoz) čini najskuplju fazu proizvodnje. Ovaj zadatak zahtijeva pravilan prostorni raspored traktorskih puteva, koji su od suštinskog značaja za privlačenje drveta korišćenjem traktora, skidera, forvardera ili animala. Visokokvalitetni prostorni raspored traktorskih puteva omogućava efikasno korišćenje drveta. Osnovni pokazatelj kvaliteta otvorenosti šuma traktorskim putevima je relativna otvorenost, pri čemu optimizacija ima za cilj da ovaj pokazatelj iznosi preko 90%, odnosno da bude odlična.

Istraživanje se fokusira na planiranje otvorenosti, odnosno optimizaciju prostornog rasporeda traktorskih puteva pomoću savremenih tehnologija, kao što su GIS alati za prostornu i statističku analizu. Ove metode omogućavaju precizno planiranje i evaluaciju trenutnog stanja, zasnovanu na terenskim, sastojinskim i infrastrukturnim uslovima. U istraživanju se kao ključni pokazatelji otvorenosti šuma određuju: gustina traktorskih puteva, prosječna daljina privlačenja i relativna otvorenost, koja služi kao glavni indikator optimalnog rasporeda traktorskih puteva.

Istraživanje je provedeno u Odjelu 65, Šumskog gazdinstva (ŠG) „Čemernica“ u opštini Kneževo. Područje istraživanja ima površinu od 39,16 hektara i karakterišu ga visoke šume bukve, jele i smrče s prirodnom obnovom, na pretežno dubokim krečnjačkim zemljištima i nadmorskim visinama od 984 do 1149 metara. Rezultati istraživanja pokazuju značajno povećanje ukupne dužine traktorskih puteva, sa 3311,15 m na 4152,15 m, odnosno gustine sa 84,55 na 106,33 m/ha. U poređenju sa sličnim studijama, gustina traktorskih puteva u ovom istraživanju se pokazala optimalnom za upravljanje visokim šumama u planinskim uslovima, dok Emrulović (2020) i Bunić (2020) navode gustine od 130 do 140 m/ha kao optimalne za slična staništa. Maksimalna gustina traktorskih puteva u Sloveniji zavisno od uslova terena se kreće od 130 do 180 m/ha (Pravilnik o gozdnih prometnicah, 2009).

Takođe, relativna otvorenost šuma u odjelu se povećala sa 80,74% za postojeću mrežu traktorskih puteva na 97,32% za nadograđenu, odnosno relativna otvorenost je unaprijeđena od vrlo dobre do izvrsne. Ukupan broj doznačenih stabala iznosi 2133, a broj stabala u otvorenim područjima oko traktorskih puteva za postojeću mrežu iznosi 1711, što daje relativnu otvorenost od 80,21%. Nakon nadogradnje mreže traktorskih puteva, relativna otvorenost povećava se na 97,23%, odnosno broj stabala u otvorenom području oko traktorskih puteva iznosi 2074, što potvrđuje da je cilj istraživanja, optimizacija otvorenosti šume,ostvaren i po jednom i po drugom kriterijumu relativne otvorenosti.

Takođe, pretpostavke da je gustina postojećih traktorskih puteva manja od 75 m/ha i da je trenutna relativna otvorenost odjela 65 manja od 70% nisu potvrđene, jer je trenutna gustina oko 85 m/ha, a relativna otvorenost oko 81%, odnosno vrlo dobra.

Ključne riječi: GIS, planiranje, privlačenje, traktorski putevi