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PLANNING OF ENVIRONMENTALLY SOUND FOREST ROAD ROUTE USING GIS & S-MCDM

PLANIRANJE OKOLIŠNO PRIHVATLJIVE TRASE ŠUMSKE CESTE POMOĆU GIS & S-MCDM

Erhan ÇALIŞKAN

Summary

Forest roads are basic precondition for the sustainable management of forest resources. These roads entail a complex engineering effort because they can cause substantial environmental damage to forests and include a high-cost construction. Therefore, the design of forest road routes should have taken into account in terms of environmental impacts. In order to do this, the Geographical Information System (GIS) with Spatial Multi Criteria Decision Making (S-MCDM) techniques is a useful tool for creating a model. One such S-MCDM is the Spatial-integrated Technique for Order Preference by Similarity to Ideal Solution (S-TOPSIS). In this study, S-TOPSIS was applied to integrate environmental impacts into the design of a forest road route. Using the current forest road route (CFOR) and the GIS-based S-TOPSIS method, an environmentally sound forest road route (ESFOR) was determined according to environmental criteria. Five environmental criteria (avalanche, river, soil, geology and slope) were used for analysis to compare with. The results obtained from the analyses, are compared to the current forest road route. The CFOR 15.385 km in length, while the ESFOR found by S-TOPSIS was 14.385 km. If the differences in length between two roads multiplied by the width of the road (1km X 5m), the result would be 0.5 ha. The results showed that this methodology can provide environmentally sound road network also help to design quickly and less costly. These results suggest that spatial multi criteria decision making method can be more accurate in terms of environmentally sensitive forest road designing in mountainous area.

KEY WORDS: Geographical Information System, Multi Criteria Decision Making, S-Topsis, forest road, environmentally sound

INTRODUCTION
UVOD

Forest roads play an important role in forest management, transportation of wood raw material protection and afforestation activities in mountainous areas (Çalışkan 2013). A well planned, designed, constructed, and maintained system of forest roads is necessary to facilitate forest management and protection of natural resources. Recognizing that office-designed preliminary route locations can save forest managers time and money and with the advent of computers, researchers and forest management consultants have produced numerous software packages to assist in the strategic, operational and tactical aspects of forest road planning (Rogers 2005;Abdulgader 2013).

The road design and construction process is the most expensive and also most damaging activities in forestry, for example; slope failures and mass movement (Duncan 1987). Forest roads are globally recognized as a main source of sediment yield and pollution of off-site water (Arneaz 2004; Forsyth 2006; Fu 2010), in addition to direct loss of habitat

Assoc. prof. dr. Erhan Çalişkan Karadeniz Technical University, Faculty of Forestry, 61080, Trabzon-Turkey, email: caliskan@ktu.edu.tr

(Geneletti 2003), and indirect loss of habitat (by the fragmentation of an ecosystem into smaller and more isolated patches) (Chomitz 1996). Forest roads, especially inefficient road networks, generate abrupt edges and, finally, cause habitat and biodiversity losses (Hui 2003). To reduce these negative impacts, forest road managers need to look for ways of developing road networks and improving the environmental soundness and public acceptance of road construction activities (Heinimann 1996; Gümüş 2008; Hayati 2013, Hernández-Díaz et al 2015).

Conventional road planning methods based on topographic maps do not allow forest engineers to create enough number of road alternatives (Chung and Sessions 2001). If the alternatives are not evaluated in the process of choosing the optimum route, the engineers cannot guarantee that the chosen route is the best one which reduces the environmental effects around the route to a minimum. In their study, Rapaport and Snickars (1998) determined a road route which reduces the environmental effects to a minimum, has a low-cost and enables transportation in the shortest period of time by using GIS techniques. Lee and Stucky (1998) developed an algorithm for finding the lowest-cost road route depending on the topography factor and they tested it via field work. Sadek et al. (1999) carried out a study in which a GIS platform was developed which brings together the content necessary for the multi-criteria evaluation of route alternatives. Enache et al. (2013) was to develop a decision support tool for evaluating different forest road options before technical design, using a participatory approach and multiple criteria analyses. Nowadays, there has been a rapid expansion of interest and research on GIS-based and Spatial MCDM methods. S-MCDM methods are interactive and flexible tools for the analysis of complexity among the alternatives which contain different environmental and socio-economic effects. Combining GIS and S-MCDM techniques provides convenience to the users in determining the various alternatives of criteria and objects having multiple and complex structures. This method provides integration of the information by comparing the alternatives with respect to selected criteria (Kesgin and Ersoy 2006; Anavberokhai 2008; Şener 2004; Malczewski 1999). Some researchers have been performing road network analyses using GIS-based road structure and multi-criteria decision making by considering factors such as wood volume, slope, soil condition, distance between existing forest roads, soil type, geology, hydrography, elevation and tree type in addition to environmental factors (Sadek et al.1999; Hosseini and Solaymani 2006; Jusoff 2008; Mohammadi Samani et al. 2010; Hayati et al. 2012; Norizah 2012; Çalışkan 2013; Pellegrini et al 2013; Tampekis 2015;Lashi et al 2016).

Forest roads entail a complex engineering effort because they can cause substantial environmental damage to forests and include a high-cost construction. Therefore, it is very important that the design of forest road routes take into

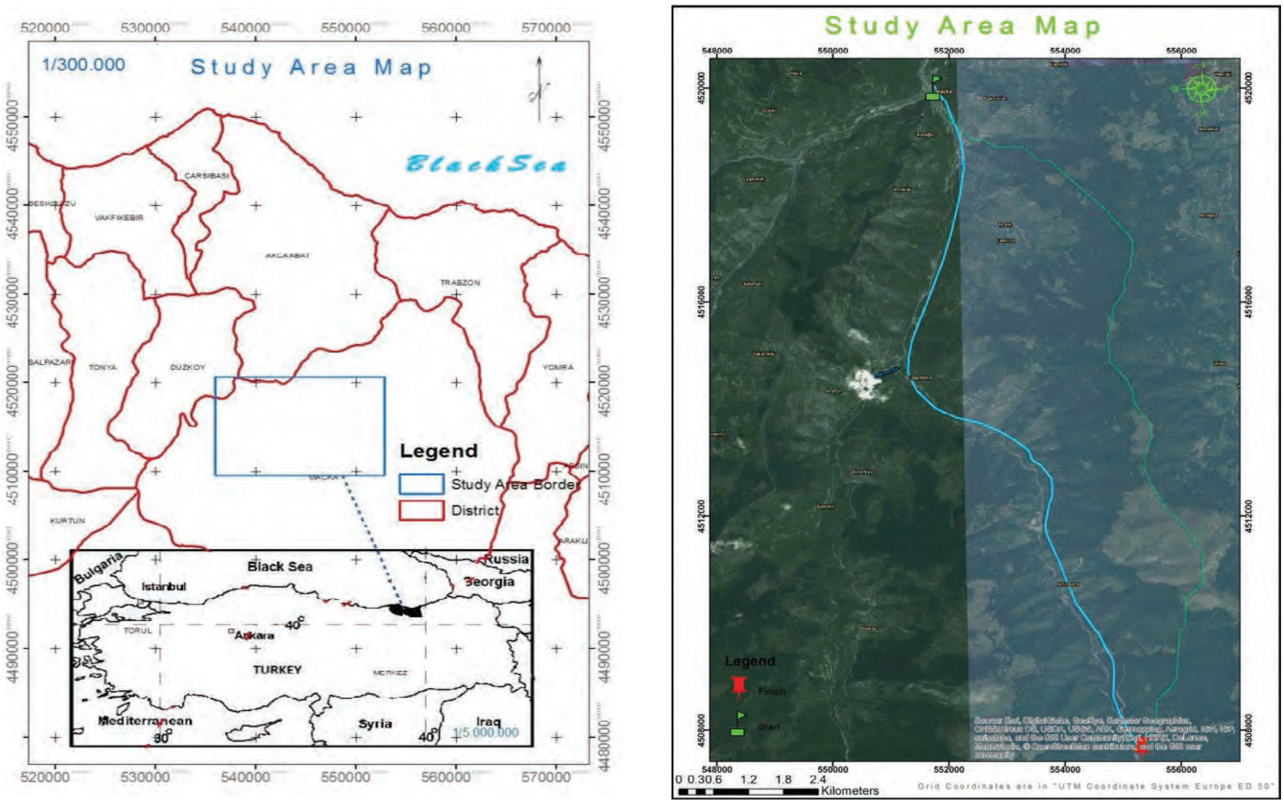

Figure 1. The location of the study area
Slika 1. Lokacija područja istraživanja

account environmental sounds. In order to do this, the GIS used with S-MCDM techniques are a useful tool for creating a model. One such MCDM is the S-TOPSIS. In this study, S-TOPSIS was applied to integrate environmental sensitive into the design of a forest road route. Using the current forest road route and the GIS-based S-TOPSIS method, an environmentally sound forest road route was determined according to environmental criteria.

MATERIALS & METHODS
MATERIJAL I METODE

Research area – *Područje istraživanja*

Trabzon Province is situated between longitude 39° 7' 30'' and 40° 30' E and latitude 40° 30' to 41° 7' N in the middle of the east Black Sea region of Turkey (Figure 1). East Blacks Sea region and also Trabzon city is green-field and has great tree diversity due to rainy climate. There are many different stands at Trabzon and in case study area chosen. Determining an optimum route for a road in this area is a challenge. The location of the study area is shown in Figure. 1.

METHOD
METODE

The research method in this article consisted of five steps. The first step, the forest road designing area was determined (Figure 1). In the second step, the data required to design the forest road route, considering environmental criteria, was collected within the boundaries of the research area. In this step, existing data from satellite images, soil data, hydrology data, geology data, GPS data and standard 1/25,000-scale topographical maps were used and the data organized in a spatial database. In the third step, factors and sub-factors were determined, and weights of these factors and sub-factors were calculated. In the fourth step, the optimum environmental forest road route was determined based on S-TOPSIS and Cost distance-Cost path algorithms using the weights of the factors affecting the route. The final step was to compare the current forest road route and the optimum forest road route with the results of field studies and spatial data and to discuss the results.

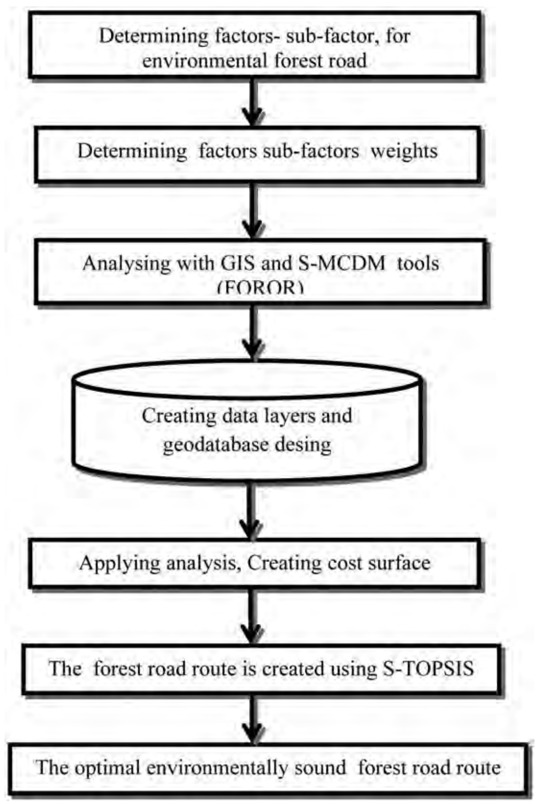

Figure 2. Conceptual framework of this study
Slika 2. Konceptualni okvir istraživanja

A geographic database was created in ESRI ArcGIS10.3 software and projected to Universal Transverse Marketer (UTM) projection, zone 36N. Maps were rectified, digitized, projected and imported to the geographic database. A conversion to raster format was performed using a cell size of 30x30 m. The developed conceptual framework is presented in the Figure 2.

An accurate and updated geodatabase was created consisting geographic layers in environmental factors. Geographic layers were redesigned flowingly due to sub-factors including in factors. These layers in geodatabase are; rivers, elevation, soil type, geology, avalanche, and slope map of area. Common S-MCDM rules and formulae have been used for calculating factor and sub-factor weights with our special extension (FOROR). This extension named Forest Road Route (FOROR) is a comprehensive tool automating all the analysis. The functionality of the extension is gathering GIS and S-MCDM features within the same interface for finding forest road routes. GIS&S-MCDM extension for ArcMap 10.3. we used Microsoft Visual Studio and ArcGIS SDK (Software Developer Kit) for Python using ArcObject libraries. A pair-wise comparison and S-TOPSIS formulas have been implemented in the extension.

GIS analysis processes are interpolating heights and building TIN, ring-buffer for river, way etc. point or polyline data and then merging them with the study area border, interpolating some sample data (like population) with Kriging or IDW as geostatistical coherent interpolation techniques and reorganizing polygon data before applying raster to vector conversation. Finally, all the geospatial dataset prepared in vector format was clipped to the study area border and converted to raster format in equivalent pixel values for calculating the accumulated cost surface with S-TOPSIS formulas included in the extension. Cost distance-cost path algorithms were applied to accumulated surfaces and optimum environmental routes were found.

S-TOPSIS – *S-TOPSIS*

The TOPSIS (technique for order performance by similarity to idea solution) was first developed by Hwang & Yoon (1981). According to this technique, the best alternative would be the one that is nearest to the positive-ideal solution and farthest from the negative ideal solution (Ertugrul et al 2007). The positive-ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang et al 2006). In short, the positive-ideal solution is composed of all best values attainable from the criteria, whereas the negative ideal solution consists of all worst values attainable from the criteria (Wang, 2007). There have been lots of studies in the literature using TOPSIS for the solution of MCDM problems. (Chen, 2000; Chu, 2002; Chu and Lin, 2002;Lai et al., 1994;Olson 2004; Wang et al., 2005; Yang et al 2007; Dağdeviren et al 2009 and Yıldırım et al 2016). The TOPSIS method consists of the following steps (Shyur et al 2006): Variables at the equation sequence of TOPSIS calculation and these variables are defined below:

D = decision matrix
A1, ……, An = value corresponding to *jth* alternative
F1, ……, Fn = value corresponding to *ith* criteria (factor)
R(=[rij]) = normalized decision matrix
Vij = weighted normalized matrix
Wi = weight of any criteria (factor)
A+ = positive ideal solution
A– = negative ideal solution
Dj+ = separation measures to positive-ideal solution
Dj– = separation measures to negative-ideal solution
CCj+ = relative closeness to the ideal solution

Step 1: Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{array}{cccccccc} & F_1 & F_2 & .. & F_j & .. & F_n \\ A_1 & f_{11} & f_{12} & .. & f_{1j} & .. & f_{1n} \\ A_2 & f_{21} & f_{22} & .. & f_{2j} & .. & f_{2n} \\ .. & .. & .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. & .. & .. \\ A_3 & f_{i1} & f_{i2} & .. & f_{ij} & .. & f_{in} \\ . & .. & .. & .. & .. & .. & .. \\ . & .. & .. & .. & .. & .. & .. \\ A_J & f_{J1} & f_{J2} & .. & f_{Jj} & .. & f_{Jn} \end{array} \qquad (1)$$

where A_j denotes the alternatives j, $j = 1, 2,\dots, J$; F_i represents the ith attribute or criterion, $i = 1, 2,\dots, n$, related to the ith alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j.

Step 2: Calculate the normalized decision matrix R (= $[r_{ij}]$). The normalized value r_{ij} is calculated as

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}}, j = 1, 2,\dots, J; I = 1, 2,\dots, n \qquad (2)$$

Step 3: Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value v_{ij} is calculated as

$$V_{ij} = w_i \text{ x } r_{ij}, \qquad j = 1, 2,, J; I = 1, 2,\dots, n \qquad (3)$$

where w_i represents the weight of the ith attribute or criterion.

Step 4: Determine the positive-ideal and negative-ideal solutions.

$$A^+ = \{v_1^+, v_2^+, \dots, v_i^+ = \{(\max v_{ij} | i \in I'), (\min v_{ij} | i \in I'') \qquad (4)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_i^- = \{(\min v_{ij} | i \in I'), (\max v_{ij} | i \in I'') \qquad (5)$$

where I' is associated with the positive criteria, and I'' is associated with the negative criteria.

Step 5: Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the positive-ideal solution $[\![(D]\!]_i^+)$ is given as

$$D_j^+ \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2}, \qquad j = 1, 2, \dots, J \qquad (6)$$

Similarly, the separation of each alternative from the negative-ideal solution $[\![(D]\!]_i^-)$ is as follows:

$$D_j^- \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2}, \qquad j = 1, 2, \dots, J \qquad (7)$$

Step 6: Calculate the relative closeness to the ideal solution and rank the performance order. The relative closeness of the alternative A_j can be expressed as

$$CC_j^+ = \frac{D_j^-}{D_j^+ + D_j^-}, \qquad j = 1, 2,\dots, J \qquad (8)$$

Since $D_j^- \geq 0$ and $D_j^+ \geq 0$, then clearly $CC_j^+ \in [0,1]$, The larger the index value, the better the performance of the alternatives.

As can be seen above, S-TOPSIS is an efficient method in the model of Multicriteria Decision Support Systems. The factor and sub-factor weights were calculated using S-TOPSIS.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

GIS-based S-MCDM was employed as a new approach to produce the forest road route. S-TOPSIS is widely used to solve S-MCDM problems and is proposed by Hwang and Yoon 1981.At this stage, subsequent to determining the weights of the criteria and indices using spatial analysis, the final weight of the routes was calculated using the S-TOPSIS method. GIS based S-MCDM analyses were applied on geodatabase using our case-sensitive extension (FOROR).

The optimal route was created using S-TOPSIS with GIS-based FOROR. ArcGIS 10.3 software was used and an interface was able to identify routes through raster data models for the cost distance-cost path algorithms designed on this software using S-TOPSIS. In this process, all data layers were formed using raster-based standard pixel sizes. The pixel sizes were determined, depending on the scale of the used spatial data, as 30X30 m in order to avoid loss of data. In this study we have determined the weights with a comprehensive survey to academicians, private sector and forest engineering staffs working at similar route determination areas. S-TOPSIS methodology must be started at the second step (the steps of the TOPSIS are given in Section). Thus, weighted normalized decision matrix can be prepared. A pair-wise comparison and normalized weight table are given in Table 1. The weight values shown in Table 1 were multiplied with the data layers and the resulting values were designated as the cost to each layer pixel. At figure 3, some of these geographic layers are shown.

Table 1. Factors, sub factor weights
Tablica 1. Čimbenici, podčimbenici, težina

CRITERIA KRITERIJI	(Factor) PASSING (Čimbenik) PROLAZ	(Sub Factor) Weight (Podčimbenik) Težina
Avalanche *Lavina*	Pass	9
Rivers	100m	9
Rijeka	150m	7
*Soil	4	5
Tlo	6	3
	7	2
Geology	Kru 1-2-3	1
Geologija	Gama 2-3	7
	Jlh-Jkr	5
	Alv	4
Slope(%)	0–5	1
Nagib	5,01–10	3
	10,01–20	5
	20,01–30	7
	30,01–40	9
	40,01–90	9

*Soil type is shown with numbers from 1 to 9. 1 is the best quality soil for agriculture or other usages, other side 9 is poor quality soil

Table 2. Comparison of routes in terms of environmental criteria
Tablica 2. Usporedba trasa u smislu ekoloških kriterija

	CFOR	ESFOR
Length (m) *Dužina*	15385 m	14385 m
Avalanche Risk *Lavina*	1 Risk	No Risk
River Proximity *Rijeka*		
100 m	11636	1883
100–150 m	1382	435
Soil Quality *Tlo*		
4. th Quality	370 m	198 m
6. th Quality	–	4368 m
7. th Quality	14014 m	10768 m
Geology-Litology *Geologija*		
Gama	3185 m	4411 m
Jlh	1015 m	551 m
Jkr	1053 m	487 m
Kru 1-2	9130 m	9884 m
Slope (%) *Nagib*		
0–5	460 m	637 m
5–10	503 m	959 m
10–20	2103 m	1608 m
20–30	3000 m	4422 m
30–40	4768 m	4210 m
40–90	910 m	3597 m

In accordance with these criteria, an Environmentally Sound Forest Road Route (ESFOR) was determined with S-TOPSIS and its advantages as compared to the current forest road route (CFOR) are shown in Table 2.

ESFOR is more effective than conventional methods and can be easily seen at Table 2. ESFOR is advantageous to CFOR when the five criteria considered separately. CFOR and ESFOR routes were also compared with field studies. Advantageous and disadvantageous aspects of the two routes are clearly seen in the visiting area. There was great consistency between analysis results and field observations.

However, the important advantage of this ESFOR is that it is much shorter than the other CFOR and thus has a lower cost. This can be a very important advantage, as road construction is very costly. A cost surface map created (cost) values assigned as resistance in order to determine the environmentally sound of the forest road route in each pixel (Figure 4).

Forest road route with the lowest total construction costs is not always the best solution from an environmental point of view (Liu and Sessions 1993; Dean 1997; Chung and Sessions 2001; Aruga 2005; Akay 2006; Hayati et al. 2013). One of the main factors in forest road route was considering the costs of road construction and maintenance during

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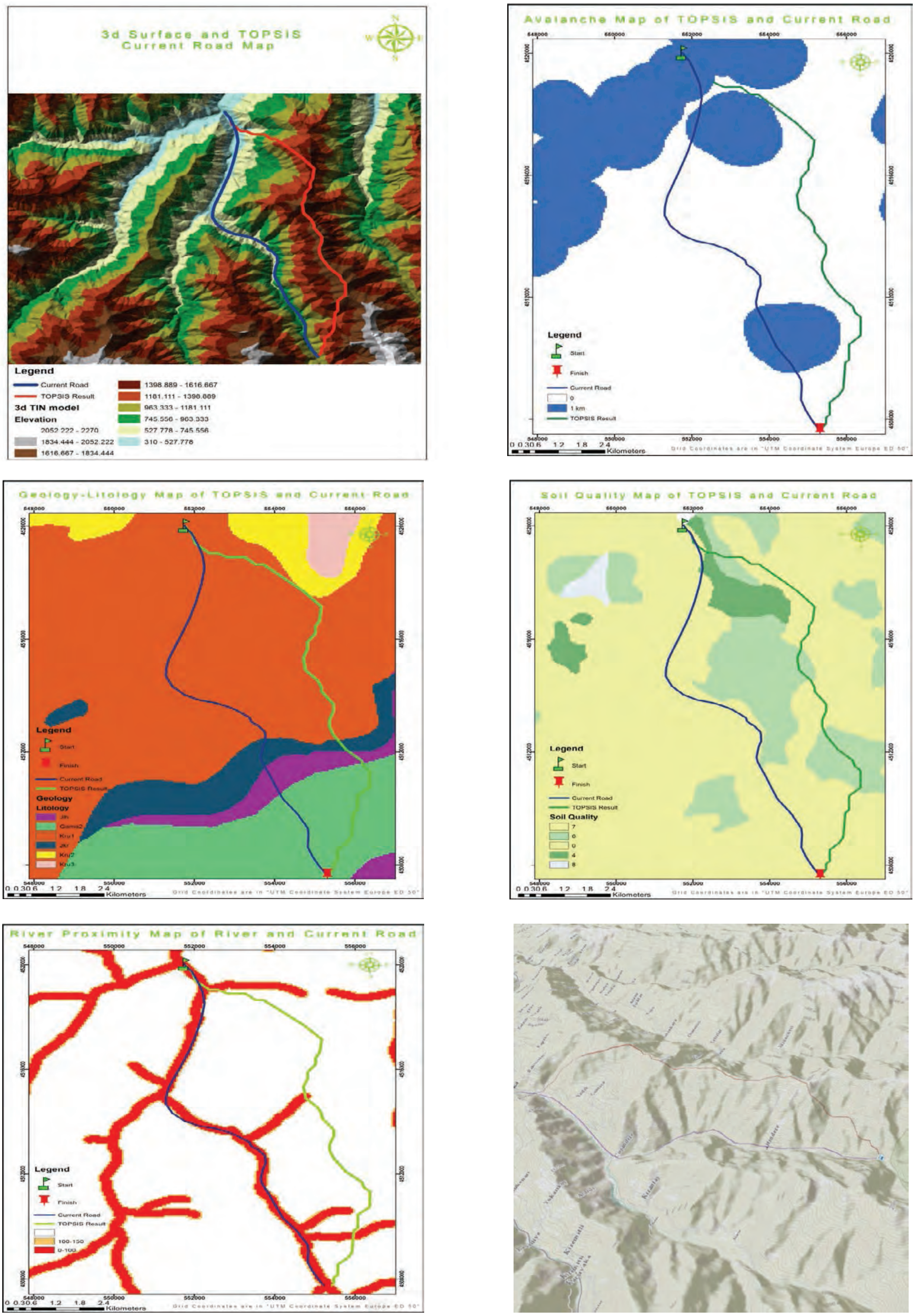

Figure 3. Maps of some geographic layers in Geodabase (3d surface, avalanche, geology, soil, river, slope)

Slika 3. Mapa nekih geografskih slojeva u Geodatabase(dem površina, Lavina, Geologija,Tlo, Rijeka,Nagib)

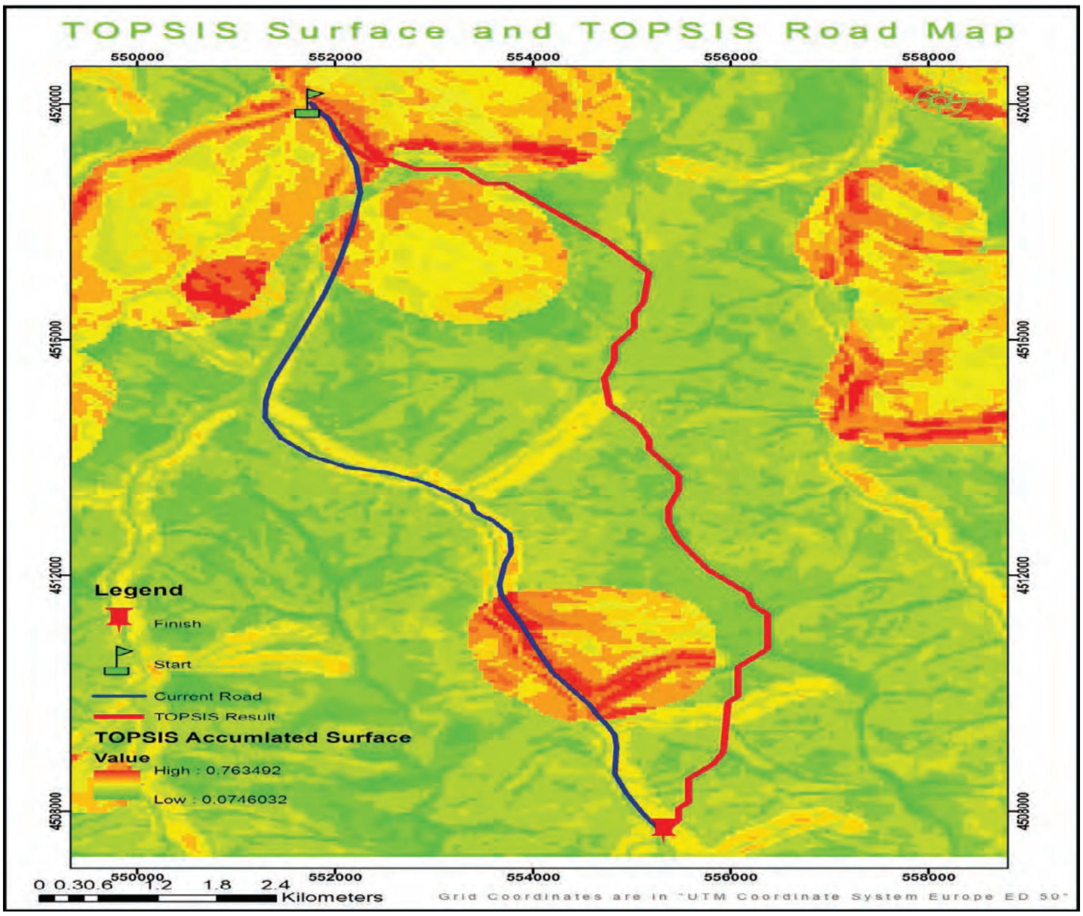

Figure 4. S-TOPSIS cost surface, S-TOPSIS route and current forest road route
Slika 4. Površina troškova S-TOPSIS, S-TOPSIS trasa i sadašnja trasa šumske ceste

the initial route location in the field. In this context, S-MCDM methods and GIS-based forest road route determination applications are very important. S-MCDM integrated with GIS is one of the Multi Criteria Decision Methods. Spatial Technique for Order Preference by Similarity to Ideal Solution (S-TOPSIS), spatial analytic hierarchy process (S-AHP), spatial promethee (S-PROMETHEE), and spatial simple additive weighting (S-SAW) are the most commonly used of these methods. In this study, S-TOPSIS was used. In previous scientific studies, S-AHP work has been widely used and the advantages of this method have been clearly studied (Majnounian et al., 2007;Abdi at al.,2009;Naghi et al., 2012;Hayati et al., 2012; Hayati et al., 2013; Çalışkan, 2013; Pellegrini et al 2013; Lashi et al 2016). In future studies, results can be proven by using other spatial S-MCDM methods. Enache et al. (2013) which used the weighted preferences of the evaluation sub-criteria reported in this study to calculate the total utility scores of four forest road scenarios using MAUT.

The GIS has many effective tools which enable the use of analytic functions. The GIS has the capability to combine thematic data layers to create a cost surface from which the optimal forest road route is calculated. The S-MCDM method integrates GIS technologies with complex decision-making in a way that provides a successful outcome (Yıldırım et al 2016b). This study demonstrated the increased effectiveness of integrating GIS technologies with S-TOPSIS, especially in forest road route.

CONCLUSION
ZAKLJUČCI

In this study, S-TOPSIS was applied to integrate environmentally sound into the design of a forest road route. Using the current forest road route and the GIS-based S-TOPSIS method, an environmentally sound forest road route was determined considering environmental criteria's. The environmental factors which affect the forest road route and necessary geographic data layers were determined accordingly and were then classified according to the standards. Analyses were performed using this method for the design of forest road routes. The S-TOPSIS method was effectively used in applications of cost distance-cost path algorithms based on GIS. This study has provided very positive results in the determination of forest road routes with the advantage of the algorithm used in the calculation cost surface. The current forest road route (CFOR) is 15.385 km in length, while the ESFOR found with S-TOPSIS was 14.385 km. It was proven that environmental damage due to road construction could be prevented on about 0.5 ha.

These results suggest that GIS and spatial multicriteria decision method can be more accurately to design forest road route in mountainous area. The results showed that this methodology can be more helpful and road network can be designed more quickly and less costly.

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Sažetak

Šumske ceste su osnovni preduvjet za održivo upravljanje šumskim resursima. Te ceste uključuju složene inženjerske napore, jer mogu izazvati znatnu ekološku štetu šumama i uključuju vrlo skupu izgradnju. Stoga pri izrada trasa šumskih cesta, treba uzeti u obzir i utjecaj na okoliš. Da bi se to i napravilo, geografski informacijski sustav (GIS) s tehnikama prostornog višekriterijskog donošenja odluka (S-MCDM) koristan je alat za izradu modela. Jedan takav S-MCDM je prostorno-integrirana tehnika preferiranja sličnosti do idealnog rješenja (S-TOPSIS). U ovoj studiji S-TOPSIS primijenjen je za integriranje ekoloških učinaka u izradu trase šumske ceste. Korištenjem sadašnje trase šumske ceste (CFOR) te S-TOPSIS metode na temelju GIS-a, utvrđena je ekološki osjetljiva trasa šumske ceste (ESFOR) prema ekološkim kriterijima. Za usporedbu korišteno je pet ekoloških kriterija (lavina, rijeka, tlo, geologija, nagib). Rezultati dobiveni iz analiza uspoređeni su sa sadašnjom trasom šumske ceste. Dužina CFOR-a je 15.385 km dok je ESFOR utvrđen S-TOPSIS-om bio 14.385 km. Da se razlike u dužini između dviju cesta pomnože sa širinom ceste (1 km x 5 m) rezultat bi bio 0,5 ha.

Rezultati su pokazali da ova metodologija može pružiti ekološki osjetljivu mrežu cesta, te može pomoći u bržoj izradi i biti jeftinija. Ovi rezultati sugeriraju da metoda prostorne procjene višestrukim kriterijima može biti točnija u smislu izrade ekološki osjetljivih šumskih cesta u planinskim područjima.

KLJUČNE RIJEČI: Geografski informacijski sustav, višekriterijsko donošenje odluka, TOPSIS, šumska cesta, ekološki osjetljivo