# Planning Forest Accessibility with a Low Ecological Impact

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***Abstract – Nacrtak***

*This paper examines a new approach to forest accessibility planning based on a GIS road development algorithm and some topographically derived indices. The aim of the paper is to propose and validate a method of assessing forest accessibility introducing an ecological approach, based on morphological impact. For the case study, both cartographic material (DEM) and measured items (existing road network) were used in applying the method. The case study offered the data and possibility to analyze, compare and take into consideration the ecological impact on planning forest accessibility.*

*Keywords: planning, forest accessibility, ecological impact, soil erosion, GIS*

## 1. Introduction – *Uvod*

Romanian forest lands extend over 6.3 million ha, representing 27% of the total area of the country. The distribution of forest lands is such that 90% of it is on terrain classified as hills or mountains. Hence, it follows that the majority of forestry works are carried out on rough topography, where the slopes frequently account for more than 25% of the whole area.

Forest accessibility is low due to the lack of adequate access roads. From a total of 6.3 million ha of forest land, only 4.1 million ha could be considered accessible; the rest of these forest lands are not connected to an existing transport system. The road density of the forest road network is 6.2 m/ha (Iordache 2007). At present, the available forest transport system (truck roads, narrow gauge railways, public roads, servicing roads) consists of 39,186 km intended to cover various forest activities.

Forestry production always covers considerable areas and from the point of view of natural forest management simple road construction is not sufficient. According to Dietz et al. (1984) and Dürrstein (1998) a proper forest opening has always to be developed in a sequence of stages:

⇒ connecting the forest to the public transport system (roads, railroads),
⇒ access to the different parts of the forest,
⇒ access to the single compartments or units of the forest.

Due to low road density in Romania, planning of forest accessibility remains a main issue in further development of the road network. Taking into consideration ecological principles, like soil erosion, terrain disruption, GIS based algorithms can offer a sustainable ecological planning of forest accessibility (Iordache and Nita 2008).

The main ecological impact made by road development can occur by landsliding from road surfaces during plantation harvest and post-harvest periods. It is estimated that 50–90% of sediment in planted forests comes from roads (Fransen et al. 2001). Sediments from roads can have a bigger environmental impact than landslide sediments because of the higher concentrations of fine sediments (Elliot et al. 1993, Fahey and Marden 2000, Hicks and Harmsworth 1989). Sediment may affect water habitats and landscape ecology by affecting the natural flow of the rivers and perturbing geomorphic channel processes by excessive sedimentation.

Quantifying possible morphological impact from forest roads represents an important issue both for road planners and for decision makers. This can either be done by implementing potentially expensive erosion control measures after the road network has been established or by designing the forest road network in a way to minimize erosion (Cochrane et al. 2007).

This is why the aim of the present study is to propose and validate a method of road network development that takes into consideration areas with high occurrence of ecological perturbation. The purpose of research is to allow forest road planners to minimize the impact of forest roads on morphometry and consequently on habitats and ecology.

## 2. Material and Methods – *Materijal i metode*

The research material included an existing road network divided into 11 road segments situated in Lesuntu Mare Upper Watershed (Fig. 1). This watershed is situated in a mountainous area of Carpathian Mountains.

The following research materials were used:

⇒ Cartographic data – DEM extracted from topographic contour lines, having a 5 m cell size (pixel) and 1 m height accuracy (according to topographic plan specifications),

⇒ Measured data – 11 road segments measured in the field with a handheld GPS (3 m accuracy).

The method itself contains the following calculating steps:

⇒ Preparatory– correcting the DEM by removing sinks and peaks,

⇒ Accessibility calculation – calculating the accessibility distance from every cell to road network.

Accessibility was calculated using cost function GIS based algorithm developed in ArcMap 9.2. From the cell perspective, the objective of the cost functions is to determine the least costly path to reach the

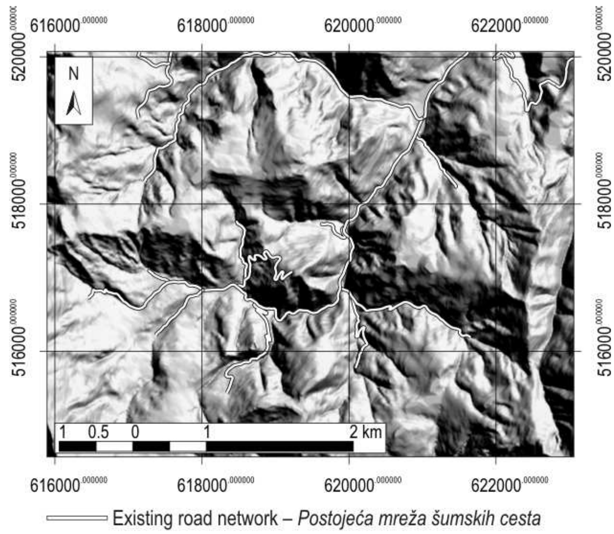


**Fig. 1** Location of the studied forest road network
***Slika 1.*** *Položaj istraživane mreže šumskih cesta*

cell from the least costly source for each cell location in the analysis window. For each cell, determination was made of the least accumulative cost path from a source, the source that allows for the least cost path, and the least cost path itself.

The formula used by algorithm to calculate the total cost from one cell to another is:

$$\text{Cost\_dist} = \frac{\text{Surface\_dist} \cdot \text{Vertical\_factor} \cdot (\text{Friction} \cdot \text{Horizontal\_factor})}{2} \quad (1)$$

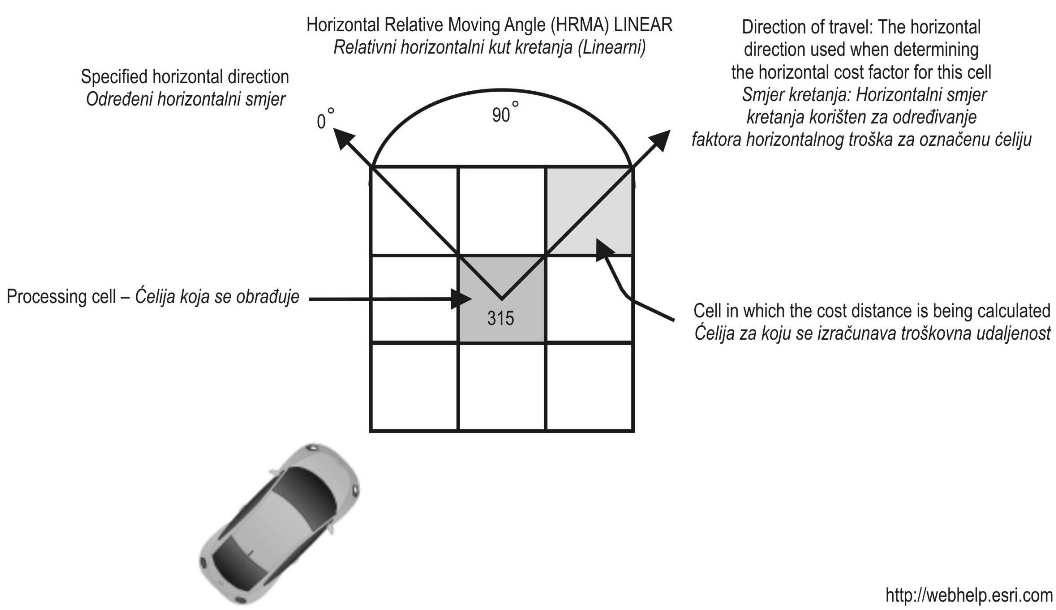


**Fig. 2** Determination of horizontal factors
***Slika 2.*** *Određivanje horizontalnih faktora*

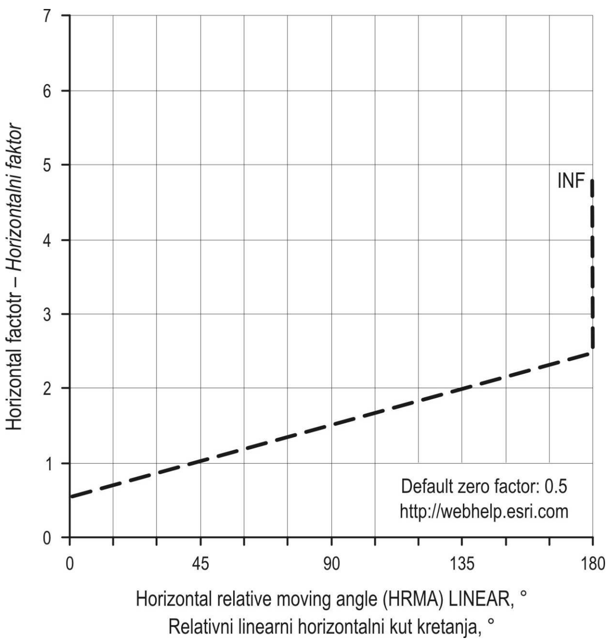


**Fig. 3** Horizontal factor dependence function
***Slika 3.*** *Funkcija ovisnosti horizontalnoga faktora*

The horizontal factors determine the difficulty of moving from one cell to another while accounting for the horizontal elements that may affect the movement. To determine the HF for moving from one cell to the next, the prevailing horizontal direction at the processing cell was established from the horizontal direction raster (Fig. 2). A linear function was used as horizontal factor function, (Fig. 3), in order to set the algorithm to stop any distance calculation over the ridges.

Data analysis involves four steps:

⇒ Inaccessible area identification – based on accessibility raster, a threshold was used in order to identify areas situated more than 500 m away from the network.

⇒ Morpho–Ecological impact assessment – calculating ruggedness index and determining the possible ecological influence of the new road. The topographic ruggedness index (TRI) was developed by Riley et al. (1999) and is used to express the amount of elevation difference between adjacent cells of a digital elevation model. The calculus uses the difference in elevation values of a central cell and the neighboring cells. TRI is then derived and corresponds to average elevation change between any point on a grid and the surrounding area. Habitats and many factors influencing them (micro-climate, humidity, soil layer, etc.) directly correspond to morphometry (slope, aspect, curvature). Higher slopes influence shallow soil layers, lower humidity and therefore harsh ecological conditions. From this point of view, TRI supports an easy way for determining the areas where a forest road construction can lead to higher ecological impact than in normal conditions.

⇒ Mapping the zones with the highest ecological risk – The proposed method uses both the cost distance grid and topographic grids for better quantifying the areas where the forest accessibility provides the lowest ecological impact.

⇒ Tracing the areas for the best placement of the new roads.

## 3. Results and discussion – *Rezultati i rasprava*

The digital elevation model was used for calculating Lesuntu Mare Upper Watershed forest accessibility (Fig. 4).

By setting the distance threshold to up to 1 km to the nearest road, the resulting grid was divided in 2 areas: accessible and inaccessible forested areas (Fig. 5).

This first step in the proposed methodology offers a useful geographic distribution of the inacces-

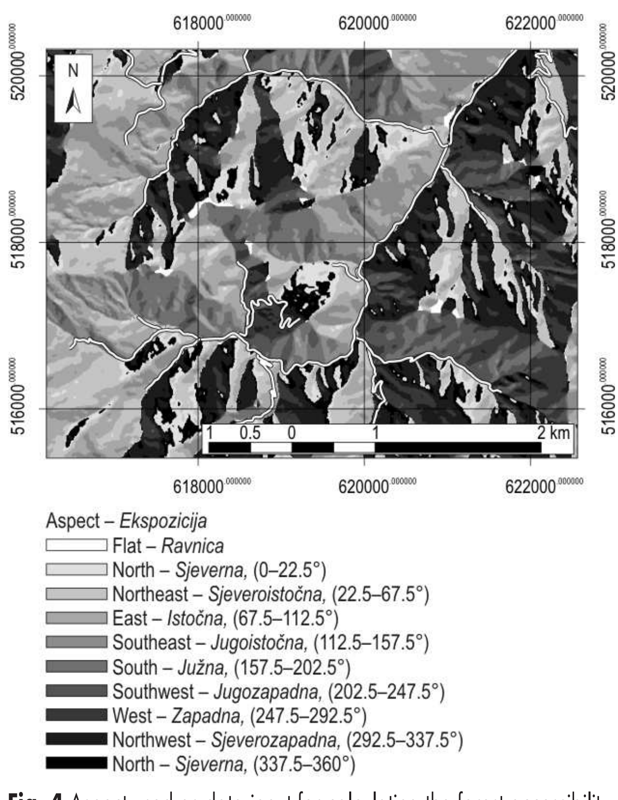


**Fig. 4** Aspect used as data input for calculating the forest accessibility
***Slika 4.*** *Ekspozicija korištena kao ulazni podatak za izračun pristupačnosti šumi*

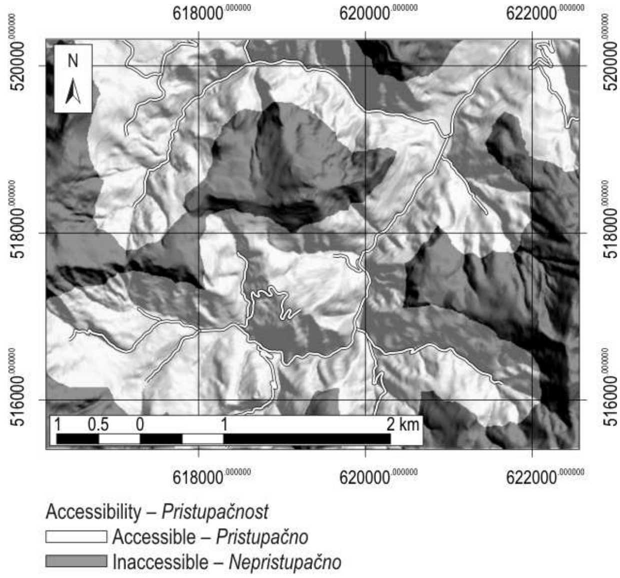


**Fig. 5** Accessible and inaccessible forested zones
***Slika 5.*** *Pristupačna i nepristupačna šumom obrasla područja*

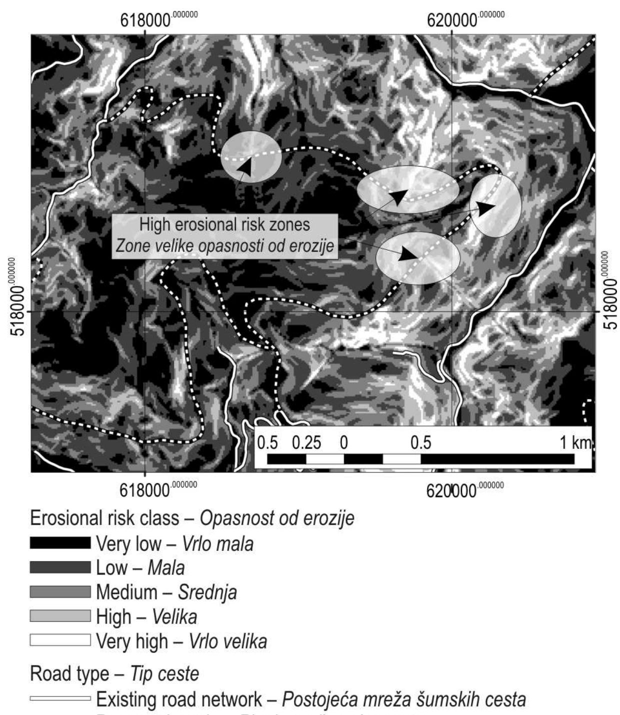


**Fig. 6** Mapping the zones with the highest erosion risk
***Slika 6.*** *Kartiranje područja s najvećim rizikom od erozije*

sible forested areas, which is a key goal for forest road planners and forest managers.

For example taking a compact area and using GIS tools the next compartments were found as inaccessible: 113B, 127C, 126E, 123C, 123D, 118B, 118D, 118C, 126D, 120A, 119B, 124B, 123B, 125A, 126B, 126F, 127B – in total 262 hectares.

Using traditional road planning methods, a possible route was created in order to increase accessibility in these compartments.

Using the ruggedness index (Riley et al. 1999), the erosion risk zones were derived in order to identify the zones where higher ecological impact of the roads could be expected (Fig. 6). Knowing these areas, some road sections were marked as highly prone to erosion.

In practice two recommendations appeared to fit in this issue:

⇒ either change the course in order to detour the zones with high ecological impact,

⇒ either apply an additional cost to those sections in order to compensate the ecological impact if no other solution is possible.

The application of the method is simple and requires few input data. The computational time depends directly on the area of digital elevation model, which affects the application of the simulation.

Using the above method by adding accessibility to 262 hectares, the results revealed possible additional costs in 4 road segments. This simulation offered additional information not only about the costs that can occur, but also about the specific zones characterized with a high probability of erosion processes.

## 4. Conclusions – *Zaključci*

From the very beginning, planning and building forest roads have severely impacted the ecosystem. The idea of identifying the areas with low ecological impact is not a new one but it cannot be identified in the methods of forest road planning. The complexity of the phenomenon is a special problem.

With the above method, the purpose of this paper was to underline that using a GIS application and geospatially referenced data, the path with the lowest ecological impact on the soil and indirectly on the ecosystem can be easily identified.

Depending on the accuracy of the data input, the output can either result in a large scale planning (based on SRTM model or other global models), or in a small scale planning and management (based on the model developed with LIDAR techniques or topographical measurements). The output data not only offered the estimation of the potential risk to the zone, but additionally also offered geographic information on the method outcome.

The proven fact that planning forest accessibility based on low ecological impact can be done based on real and accurate data will be a strong and sustainable argument to support this approach in practice.

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## Sažetak

# *Planiranje otvaranja šuma na osnovi okolišne pogodnosti*

*U ovom se radu istražuje mogućnost planiranja otvaranja šuma primjenom GIS-a temeljem mreže šumskih cesta te nekih topografskih izvedenih indeksa. Cilj je rada predložiti i potvrditi metodu procjene pristupačnosti šume uvođenjem ekološkoga pristupa s obzirom na morfološki utjecaj. Za potrebe studije te primijenjene metode korišteni su kartografski podaci (DEM – digitalni model terena) i izmjereni prostorni podaci (postojeća cestovna mreža). Studija je ponudila analizu ekološkoga utjecaja na planiranje pristupačnosti šuma.*

*Područje istraživanja uključilo je mrežu postojećih šumskih cesta podijeljenu u 11 cestovnih segmenata smještenih na lokaliteta Lesuntu Mare u Karpatima.*

*U istraživanju su korišteni:*

⇒ *kartografski podaci – digitalni visinski model dobiven iz topografskih slojnica, veličine ćelije 5 m × 5 m i visinske točnosti unutar jednoga metra*

⇒ *izmjereni podaci – 11 cestovnih odsječaka (segmenata) izmjerenih na terenu s ručnim GPS-om (položajne točnosti 3 metra).*

*Sama metoda sadrži ove korake proračuna:*

⇒ *pripremni – ispravljanje (korigiranje) digitalnoga visinskoga modela uklanjanjem vrhova i dolova (najvećih i najmanjih vrijednosti)*

*⇒ proračun pristupačnosti – proračun pristupne udaljenosti od svake ćelije do cestovne mreže korištenjem tzv. troškovne funkcije (iz grupe funkcija Spatial Analyst računalnoga programa »ESRI Arc GIS 9.2«)*

*⇒ procjena morfološko-ekološkoga utjecaja – proračun indeksa neujednačenosti terena i određivanje mogućega ekološkoga utjecaja nove ceste na okoliš*

*⇒ kartiranje područja s najvećim ekološkim (erozijskim) rizikom*

*⇒ određivanje područja za najbolji prostorni smještaj novoplaniranih cesta.*

*Za proračun pristupačnosti šumi Lesuntu Mare izrađen je digitalni model terena (slika 1). Kao funkcija horizontalnoga faktora korištena je linearna funkcija (slika 3) kako bi se odredio algoritam koji zaustavlja svaki daljnji proračun udaljenosti ako se naiđe na greben (sedlo). Postavljanjem praga udaljenosti do jednoga kilometra od najbliže šumske ceste rezultantni je raster razdijeljen u dva područja: pristupačnu i nepristupačnu šumsku površinu. Korištenjem tradicionalnih metoda planiranja cesta kreirane su moguće trase kako bi se povećala otvorenost pojedinih šumskih površina (odjela). Koristeći indeks neujednačenosti terena (Riley i dr. 1999) izlučene su zone rizika od erozije kako bi se identificirala područja u kojima bi okolišni utjecaj cesta bio veći, a gradnja nepovoljna.*

*Upotrebom metode dodatnoga troška na pojedinim odsječcima zbog kompenzacije ekološkoga utjecaja povećana je otvorenost na dodatna 262 hektara, a rezultati su ukazali na moguće dodatne troškove na 4 cestovna odsječka. Ova je simulacija ponudila dodatne podatke ne samo o troškovima koji se mogu pojaviti već i o područjima koja su izložena visokoj vjerojatnosti pojave erozije. Istraživanje je pokazalo važnost primjene GIS-a pri analizi geoprostorno referenciranih podataka kojima se jednostavno može identificirati trasa na kojoj je najmanji ekološki utjecaj na tlo ili posredno na ekosustav. Ovisno o točnosti te preciznosti unesenih podataka, izlazni se podaci mogu koristiti ili za planiranje velikih razmjera ili za planiranje i upravljanje područjima lokalnoga karaktera.*

*Ključne riječi: planiranje, otvaranje šuma, utjecaj na okoliš, erozija tla, GIS*

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