An Integrative Decision Support Tool for Assessing Forest Road Options in a Mountainous Region in Romania

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Abstract – Nacrtak

Sound development of forest infrastructure represents the backbone for sustainable forest management. However, planning forest roads, which nowadays must fulfill multiple conflicting objectives, is not an easy task. A GIS based model was developed for supporting decision making in forest road engineering. The tool allowed assessment of forest infrastructure scenarios based on multiple criteria analyses, considering stakeholders' interests, economic, ecological and social aspects. First, the decision problem was clearly structured and then criteria and sub-criteria were weighted. Then, forest road scenarios were defined and quantitative and qualitative assessments regarding infrastructure and harvesting systems were performed. In the end, utility analysis for each scenario was conducted, the forest road variant with the highest utility score being selected as the most suitable option for implementation. The model was tested and validated in a mountain forest area from Brasov County, Romania. Reduction of mean skidding distance from 864 m to 255–268 m was reported, leading to an increase in productivity of timber extraction from 7.5 m^3/h to 11.7 m^3/h and to an increased contribution margin from 21.2 €/m^3 to 25.1 €/m^3. Enhancement of forest infrastructure reduced CO_2 emissions re timber harvesting and transport from 8.52 kg/m^3 to 7.3 kg/m^3. This study showed how multiple attribute utility theory could be used in assessing different forest road options based on a participatory approach.

Keywords: forest roads, multiple criteria decision making, utility analysis, decision support tool, participatory approach

1. Introduction – *Uvod*

Enhancing forest infrastructure has always been a topic of interest among specialists in their quest to provide sound approaches for improving forest accessibility in the context of sustainable forest management (SFM). Several studies have been published regarding automation of road locating (Akay et al. 2005; Aruga 2005; Rogers 2005; Stückelberger et al. 2007) or regarding the impact of forest roads on the environment (Coulter 2004; Akay 2004). However, most of these studies are based on assessments of only one objective function. Recently, Kühmaier et al. (2010) developed a multi-attribute spatial decision support tool for selecting the best suited harvesting systems, taking into account ecological, economic and social aspects. In addition, recent studies have shown that forest roads fulfill multiple functions; they are of strategic importance in forest operations, they allow access to remote areas, in cases of natural hazards, for tourism and recreational activities (Popovici et al. 2003; Stampfer 2007; Kühmaier et al. 2010). Sustainable development of the forest infrastructure requires harmonization of road planning, designing, construction and maintenance with operational harvesting plans. Thus, planning of forest road routes and skid trails should be approached simultaneously (Pentek et al. 2007). Consideration of environmental and social aspects from the early stages of planning have also been acknowledged (Popovici et al. 2003; Gumus et al. 2008; Ciobanu et al. 2011), underlining the necessity of performing impact assessments when developing forest infrastructure. Dürrstein (1998) proposed an extensive approach system of cost-efficiency analysis of forest road options, underlining the importance of participatory process in decision making, while Heinimann (1998) stressed the planning phase should consider assessment of the technical feasibility of alternatives, environmental impact and public involvement in decision making. Though, dealing with so many variables and constraints is not an easy task for road planners and decision makers. In Romania, Zarojanu (2006, 2007) described a multi-criteria analysis model for optimizing the selection of most suitable forest road option, focusing on the technical aspects of the roads and only marginally addressing the environmental and social aspects. However, these aspects are particularly important for the development of the Romanian forestry sector. The former national strategy (Ministry of Environment and Forests – MEF 2011a) envisaged the expansion of forest infrastructure in conjunction with GIS, timber harvesting technologies and environmental constraints. Whilst several strategic actions were established in this respect (i.e. developing secondary forest infrastructure; fostering the utilization of environmentally friendly harvesting technologies), none of these have been implemented so far on large scale in Romania. Moreover, although the road density in Romanian forests is very low (6.5 m/ha, Enescu 2011), the rate of forest road network expansion is also very low (Bereziuc et al. 2003; MEF 2011b). Skidding is the main method for timber extraction, using winch tractors, skidders, gravitational hauling, ox or horse harnesses, while very few forwarders or cable yarders are used. The mean skidding distance at the national level is 1.8 km (Popovici et al. 2003), consequently with a very low productivity in timber extraction. A peculiarity of the Romanian forest sector is the timber sales procedure: on stump or at the road side. In the first case, timber is sold on stump at auctions. Contractors

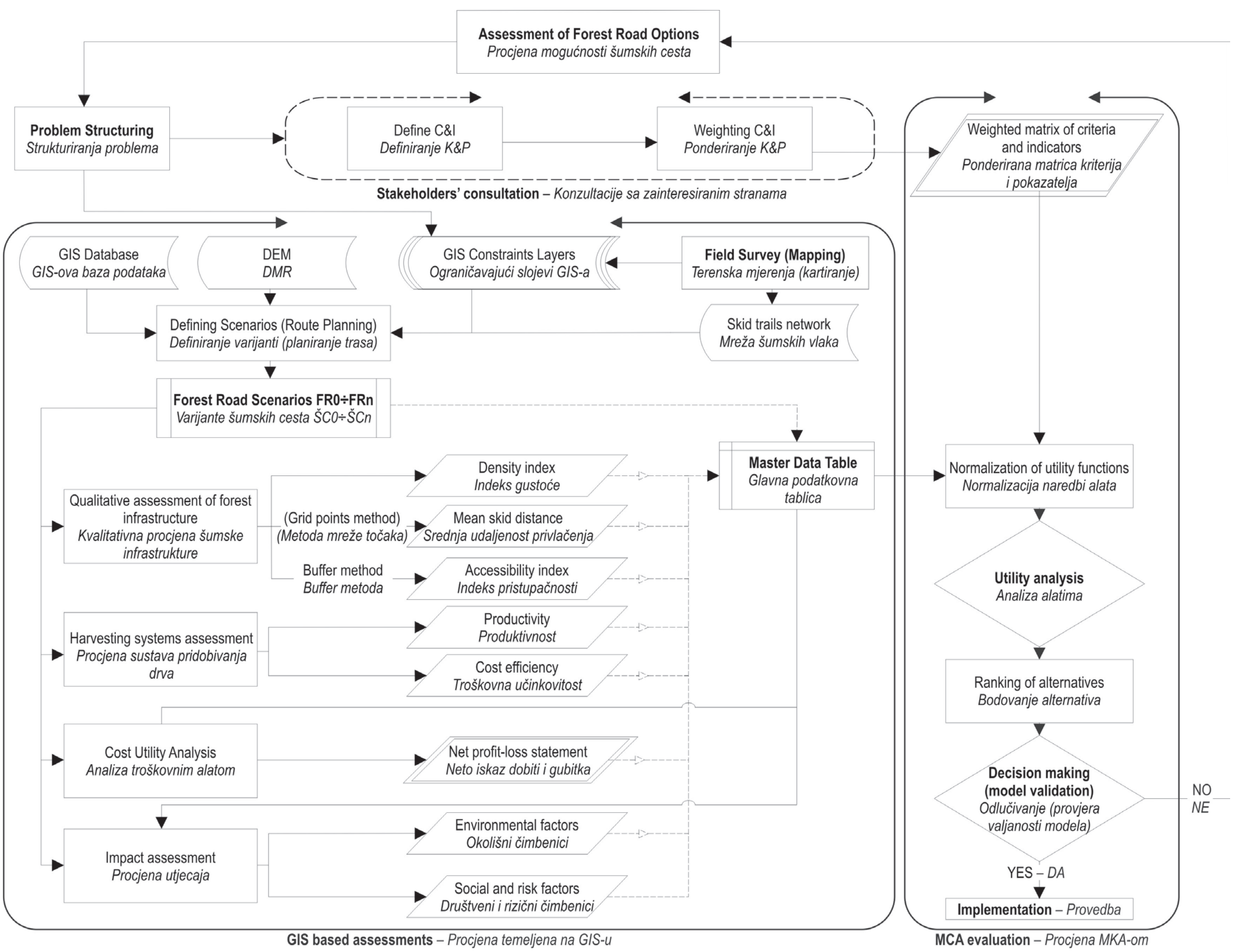

Fig. 1 Schematic representation of processes in the decision making tool

Slika 1. *Shematski prikaz procesa u alatu za odlučivanje* then harvest and sell the timber either at the road side or directly to the mill. This behavior triggered empiric development of skid trails, leading to increased residual stand damage and soil erosion. In the second case, harvesting operations are externalized by forest owners, which then sell the timber at the road side.

A well-developed forest infrastructure is a prerequisite for sustainable development of the forest sector. Thus, the traditional Romanian behavior of building valley forest roads should be changed toward building slope roads that fulfill multiple objectives (Enache et al. 2012). In Romania for decades significant emphasis

Table 1 Criteria and sub-criteria used to measure the performance of forest road alternatives

Tablica 1. *Kriteriji i potkriteriji za određivanje performansi varijanata šumskih cesta*

Criterion *Kriterij*	Sub-criterion *Potkriterij*	Efficiency Scale (Indicator) *Ljestvica učinkovitosti (pokazatelj)*	Unit *Jedinica*	Objective function *Objektivno djelovanje*
A. Management *A. Upravljanje*	A1. Independence from neighors *A1. Neovisnost o susjedstvu*	1= only own property, 0= over neighbors property *1 = samo preko vlastite imovine, 0 = preko susjedne imovine*	–	
	A2. Accessibility for execution of forest operations *A2. Pristupačnost za izvođenje šumskih radova*	% of areas in the 300 m corridor from forest roads *Postotak područja do 300 m udaljena od šumskih cesta*	%	max
	A3. Accessibility for game management *A3. Pristupačnost za lovno gospodarenje*	Maximum distance from the road to the furthest point in the project area *Najveća udaljenost od ceste do najudaljenije točke u projektnom području*	m	min
	A4. Loss of productive land (road bed clearance) *A4. Gubitak produktivne površine (oduzeto planumom ceste)*	Road length X Opening width *Duljina ceste X Oduzeta širina*	ha	min
B. Costs *B. Troškovi*	B1. Road construction costs *B1. Troškovi izgradnje cesta*	Annuity of investment effort *Renta od uloženoga napora*	€/year €/godini	min
	B2. Road maintenance costs *B2. Troškovi održavanja cesta*	Total yearly maintenance costs *Ukupni godišnji troškovi održavanja*	€/year €/godini	min
	B3. Harvesting costs *B3. Troškovi pridobivanja drva*	Total yearly harvesting costs *Ukupni godišnji troškovi pridobivanja drva*	€/year €/godini	min
C. Environment protection *C. Zaštita okoliša*	C1. Protection of ecological valuable areas *C1. Zaštita ekološki vrijednih područja*	Total cumulated distance to ecological valuable areas *Ukupno zbrojena udaljenost do ekološko vrijednih područja*	m	max
	C2. Air pollution *C2. Onečišćenje zraka*	CO_2 Emissions from harvesting machineries and timber trucks *Emisija CO_2 od strojeva za pridobivanje drva i kamiona*	kg/m^3	min
	C3. Visual disturbance of landscape *C3. Vizualno narušavanje krajolika*	Number of curves, serpentines, intersections *Broj krivina, serpentina, raskrižja*	no.	min
D. Social factors and risks *D. Socijalni čimbenici i rizici*	D1. Accidents in forest operations *D1. Nesreće na šumskim poslovima*	Time needed for first aid teams to arrive at accident location *Vrijeme potrebno za dolazak hitne pomoći na mjesto nesreće*	min	min
	D2. Risk of soil erosion and landslides *D2. Rizik od erozije tla i klizišta*	Risk factor calculated based on models of soil erosions *Čimbenici rizika izračunati na temelju modela erozije tla*	–	min
	D3. Accessibility for touristic/local/cultural purpose *D3. Pristupačnost za turističke, lokalne, kulturne interese*	Cumulated distance to the points of interest *Zbrojena udaljenost do točaka interesa*	m	min
	D4. Accessibility in case of forest fires *D4. Pristupačnost u slučaju požara*	Proportion of areas in the 200 m corridor from forest roads *Postotak područja do 200 m udaljena od šumskih cesta*	%	max
	D5. Accessibility in case of wind- throws *D5. Pristupačnost u slučaju vjetroizvala i snjegoloma*	Proportion of areas in the 300 m corridor from forest roads *Postotak područja do 300 m udaljena od šumskih cesta*	%	max

has been put merely on technical design of forest roads and only recently (Zarojanu 2007; Ciobanu et al. 2011; MEF 2012) environmental aspects have started to be considered in forest road planning.

In this particular context, the aim of this study was to develop an integrative decision support tool for evaluating forest road options based on economic, environmental and social constraints, considering multiple stakeholders' interests. The main focus was to guide decision makers in selecting the most suitable forest road option using GIS and multiple criteria analyses. The conceptual model was developed and applied in a mountain forest area in Romania and could be used in other areas with similar local conditions.

2. Material and Methods – *Materijal i metode*

Forest road engineering involves complex decision problems and conflicting objectives that need to be handled simultaneously. Technical feasibility, environmental soundness, social acceptance and economic affordability are the four main pillars on which forest infrastructure must be built (Stampfer 2007). The conceptual model, which includes all these aspects in the decision process and shows the flow of the main processes, is shown in Fig. 1. Based on this model, workflows can be performed individually or simultaneously, depending on the level of automation and on the available data sets. A master table containing sections with input and output data for each work flow process of the decision tool was created. Data from GIS databases, DEMs and forest management plan, as well as results of GIS analyses, cost appraisal, environmental impact evaluation and intermediate results of workflow processes were used as input in the overall utility analysis of the forest road alternatives.

2.1 Structuring a complex decision problem *Strukturiranje problema kompleksnoga odlučivanja*

The complex management problem of enhancing forest infrastructure requires good structuring, with clearly defined goals and objectives. Thus, based on multiple criteria decision analysis tools (Coulter 2004; Lexer et al. 2005; Green et al. 2010), the decision problem has been defined as follows: »which is the most suitable variant of the forest road that should be implemented considering multiple stakeholders' interests?«. The problem has then been hierarchically decomposed into four main objectives (criteria) and fifteen sub-objectives (sub-criteria) used in the evaluation of different forest road options (Table 1).

2.2 Multiple criteria utility model for alternatives evaluation – *Multikriterijski model korisnosti za vrednovanje varijanata*

For the evaluation of forest road alternatives based on stakeholders' preferences, multiple attribute utility theory (MAUT) has been used. One of the most applied MAUT formulas is the linear additive utility function (Kangas et al. 2008, Greene et al. 2010).

$$U_i = \sum_{j=1}^{m} a_j \cdot c_{ji}$$

U_i – the overall utility of alternative i,
c_{ji} – performance of alternative i with respect to criterion j (normalized value),
a_j – importance weight (preference) of criterion j.

The sum of preference weights is required to be 1. As sub-criteria are characterized by different efficiency scales with different measurement units, as a first step, all cardinal values of the sub-criteria were normalized to a common comparable scale. In order to do so, the score range procedure was applied, resulting in local values of each indicator, which follow an interval utility scale (Kangas et al. 2008).

$$v_i = \frac{c_i - \min(c)}{\max(c) - \min(c)}$$

where:
v_i – normalized value of criterion i,
c_i – cardinal value of alternative i in the natural scale.

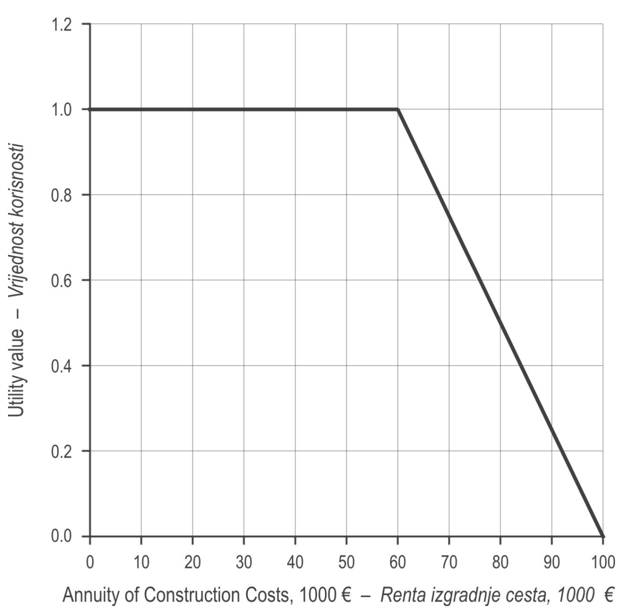

Fig. 2 Utility function for road construction costs sub-criterion
Slika 2. *Funkcija korisnosti za potkriterij trošak izgradnje cesta*

The best alternative was assumed to have the value 1, while the worst had the value 0. It was possible to define thresholds above or below which the function had a constant value. This was particularly important when referring to sub-criteria with a very big variance between alternative values. For example, in case of road construction costs sub-criterion, the linear utility function had the value 1 below 60 000 € and the value 0 above 100 000 € (Fig. 2).

Another possibility would be to use the ratio scale approach, where the criterion values for each alternative are divided with the maximum value among alternatives. Again, the best alternative has the value 1, while the worst has the value 0 (Kangas et al. 2008).

$$v_i = \frac{c_i}{\max(c)}$$

Normalized values of each sub-criterion, for each alternative, were then multiplied with their respective importance weights and then summed up, resulting in the final score of an alternative (Greene et al. 2010).

The importance weights for each criterion have been derived based on preferences of different groups of stakeholders (e.g. forest owner, forest manager, environmental protection agency, forest contractor, other authorities) from the Romanian forest sector, through a nationwide survey. Stakeholders were requested to fill their field of expertise and to rate their preferences

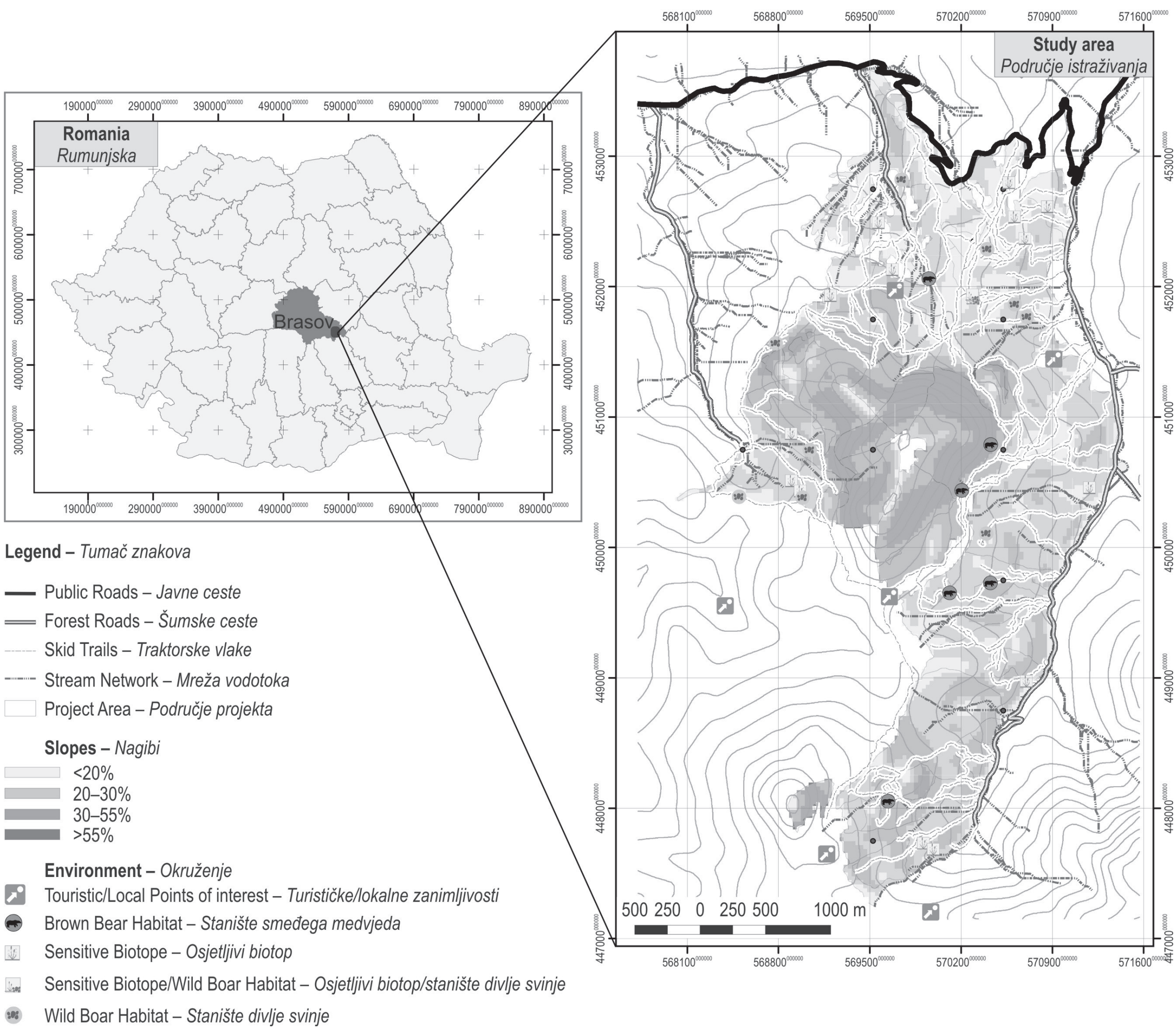

Fig. 3 Location of the study area, existing infrastructure and cardinal points (scenario Zero)

Slika 3. *Lokacija područja istraživanja, postojeća infrastruktura i ključna mjesta (nulta varijanta)* regarding the importance they gave to criteria and sub-criteria, as listed in Table 1. The preference weights were expressed on a ratio scale. The sum of preference weights for criteria had to be 100%. The preference weights given to sub-criteria of each criterion had also to sum 100%. The response rate in the survey was about 26% from the 103 successfully delivered survey forms to the stakeholders. The details regarding methodology and results of the stakeholder consultation were comprehensively presented in another study.

2.3 Study location – *Istraživano područje*

This study was conducted in a forest area of approximately 903 ha, located in Brasov County (45º55′ North Latitude and 25º90′ East Longitude), Romania (Fig. 3).

The forest is owned by the community of Tarlungeni and managed by Ciucas Autonomous Forest Administration. The forest is located at an altitude of 900–1600 m above sea level. According to the forest management plan, the most common forest types in this area are: mountain beech forests on shallow soils with mull flora; mixed fir-beech forests with mull flora of medium productivity; and beech forests with *Festuca altissima*. The geology is marly flysch, sandstones and massive conglomerates. The hydrological network includes permanent water streams, with maximum flow in spring and minimum in winter. Based on the Köppen classification presented in the forest management plan, the study area is part of the climatic province Dfck, characterized by a boreal climate (D) with precipitation varying between 750 mm and 1000 mm throughout the year (f), with average temperatures for at least three months >10ºC (c) and for at least four months >7ºC (k). The average annual temperature is 7.8ºC, the average number of days with a snow layer is 71 and the average number of days without frost is 173. One fifth of the studied forest area is located on gentle slopes (<20%), while approximately 10% is located on steep terrain (>55%). The annual allowable cut is about 4310 m^3. Other key figures are presented in Table 2.

Table 2 Key figures about study area
Tablica 2. *Glavni podaci o istraživanom području*

Forest area *Šumsko područje*	902.7 ha
Average growing stock *Prosječna drvna zaliha*	296.6 m^3/ha
Total annual growth *Ukupni godišnji prirast*	7 198 m^3
Total annual allowable cut (AAC) *Ukupni godišnji sječivi etat (GSE)*	4 308 m^3
AAC thinning *Proreda GSE-a*	1 120 m^3
AAC final cuts *Glavni prihod GSE-a*	3 188 m^3
Average timber price on stump *Prosječna cijena drva na panju*	25.3 €/m^3
Average timber price at road side *Prosječna cijena privučenoga drva*	42.6 €/m^3
Costs of felling-delimbing-sorting *Troškovi rušenja, kresanja, razvrstavanja*	7.0 €/m^3
Cleared road bed corridor width *Oduzeta širina za planum ceste*	12.0 m

2.4 Field survey – *Terenska mjerenja*

Field survey is a necessary stage prior to planning new forest roads and skid trails. Its purpose is to quantitatively and qualitatively evaluate the existing forest infrastructure. Data regarding quality of existing roads have been collected (e.g. damaged road bed, damaged bridges) and inspected elements have been categorized by causative factors. The geographic coordinates were recorded for each identified issue. In addition, a thorough survey of the project area was also performed, identifying and mapping cardinal points for road planning (i.e. possible locations of landing areas, good stream crossing points, ecologically important areas, touristic/local/cultural points of interest), while skidding trails have been mapped using a GPS for recording intervals of 5 seconds. Trails widths, stream crossings, skidding trail segments going entirely through water streams, soil erosion, average gradients and lengths of steep trails have been recorded in the data collection protocol.

For field data collection, the following instruments were used: GPS Garmin 60 CSx GPSMAP for recording geographic coordinates and for mapping skid trails network; Meridian clinometer for slope measurements; Handheld Algiz 7 rugged Tablet PC for the data collection protocol and a Laser LTI TruePulse 360 optic device for distance measurements. For data processing, ESRI® Arc GIS Desktop 10 and Microsoft Office Excel® were used.

2.5 Qualitative assessment of forest infrastructure *Kvalitativna procjena šumske infrastrukture*

This phase refers to the calculation of several structural indices of the forest road network (Pentek 2005; Bereziuc et al. 2008) based on the data from the field survey and GIS database: road density index, road distance, relative openness, geometric mean skidding distance and actual mean skidding distance. The last two indices have been derived both with analytic formulas and from analysis with ESRI® Arc GIS tools. In the latter case, the first hypothesis for deriving the geometric mean skidding distance was to assume that timber harvested from a forest management unit is concentrated into its centre of gravity and the skidding distance was calculated to these points. However, due to large sizes of management units, the accuracy of this method was very low. So, the assumption was used that harvested timber was concentrated at points located at 100 × 100 m from each other, thus resulting a grid of points based on which the mean skidding distance has been finally determined. In order to obtain the actual mean skidding distance, a correction factor was applied to mean skidding distance depending on local topography (kg). Studied literature (Segebaden 1964; Amzica 1971; Pentek 2005) mentioned correction factors varying between 1.05–1.70. For the purpose of this study, the correction factor kg was established to 1.50. Relative openness was calculated with classical formulas and by GIS analysis using the buffer method. Statistics regarding levels of forest accessibility were also performed. The automation of work flow processes was performed in Model Builder ™ extension from ESRI® ArcGIS Desktop 10. Structural indices of the skid trails network were derived in the same way as for the road network.

2.6 Assessment of harvesting systems – *Procjena sustava pridobivanja drva*

The most common harvesting methodology used in Romania is trunks and masts (Ciubotaru 1998), a method similar to the tree-length system in which trees are felled, topped and delimbed at the felling site and then extracted either as full trunks (masts) or as multiple of assortments at the road side. Extraction is usually done by winch tractors (U651) or skidders (TAF) manufactured in Romania. Pre-skidding is a specific operation in timber extraction for Romanian harvesting conditions with low density of forest roads and long skidding distances (Oprea et al. 2008). This is usually done by horse or ox harnesses at distances up to 150–200 m (Ciubotaru 1998), and refers to the transport of timber from stump to the closest skid trail. However, currently used harvesting systems in the study area are the TAF 657 skidder for final cuts and the winch tractor U651 for thinnings.

2.6.1 Assessment of productivity – *Procjena produktivnosti*

Productive system hour (PSH) is a parameter used in calculation of timber extraction costs. For the purpose of this study, productivity of harvesting systems was calculated as follows:

Since there were no specific local productivity models available, PSH of the U651 winch tractor was determined based on a logarithmic regression function derived from existing time norms (Ciubotaru 1996) that consider the following variables: group of tree species (i.e. coniferous, broadleaves), average tree volume and mean skidding distance.

PSH of the TAF 657 skidder was determined based on a recent local productivity model (Duta 2012), developed for hard-to-reach mountain regions, with similar topographic, site and infrastructure conditions as in this study.

2.6.2 Costs of harvesting systems – *Troškovi sustava pridobivanja drva*

The cost per system hour was calculated for the TAF 657 skidder and the U651 winch tractor using the FAO cost calculation scheme adapted by Holzleitner et al. (2011a), considering an interest rate of 6.5% and including the operator's costs. The input data used for calculations were the result of discussions with representatives of local forest administration.

2.6.3 Soil erosion and transport of sediments *Erozija tla i transport sedimenata*

Soil erosion and transport of sediments represent key issues in the study area. During the field survey, records were made of damages on residual stands due to timber skidding and areas with massive soil erosion (e.g. depths >150 cm) and sediment transport through water streams. Moreover, several segments of skid tracks were identified as going entirely through permanent water streams. A recent study in harvesting plots with similar site conditions (Sparchez et al. 2009) showed that most of the trees located in a buffer zone of 5 m along skid trails were damaged. An average value of soil dislocation of 40.5 m^3/ha was also reported, depending on the type of soil, harvesting method, average tree volume and local topography. In addition, Duta (2012) developed a model for quantifying soil erosion in timber skidding, based on soil type and slope grade of skid trails, reporting an average soil dislocation of 0.713 m^3 per running meter of skid trail.

2.6.4 CO_2 emissions – *Emisija CO_2*

The Kyoto Protocol calls for active action of all EU member states in reduction of greenhouse gas emissions (2002/358/CE). Under these circumstances, the impact of road construction, harvesting machinery and timber trucks on CO_2 emissions was evaluated for each infrastructure scenario. For determining the CO_2 emissions from timber transport, the assumptions were as follows: a CO_2 output factor for diesel engines of 2.65 kg/l, an average fuel consumption on forest roads of 2.05 l/km and a truck payload of 25 m^3 (Holzleitner et al. 2011b). Based on several studies on emissions from forest operations (Berg and Karjalainen 2003; Johnson et al. 2005; Markewitz 2006), the evaluation of CO_2 emissions from timber extraction was done considering a CO_2 output factor of 2.65 kg/l, PSHs of U651 winch tractor and TAF657 skidder, and fuel consumption rates of 7.5 l/h for the U651 winch tractor and 10.0 l/h for the TAF657 skidder.

Regarding road construction impact on CO_2 emissions, Loeffler et al. (2008) reported a rate of 3.8 t CO_2/km of forest road built in mixed profile on slopes with gradients less than 50%, for a CO_2 output factor of 2.73 kg/l of diesel. Karjalainen and Asikainen (1996) noted a value of 3.3 t CO_2/km for forests road built in Finland and for a CO_2 output factor of 2.66 kg/l.

2.7 Forest road scenarios – *Varijante šumskih cesta*

The focus of this paper was on the effect that enhancement of forest infrastructure alone had on the current management practices, without considering any changes in harvesting systems. However, the improvement of forest infrastructure created the conditions for adapting current timber extraction practices

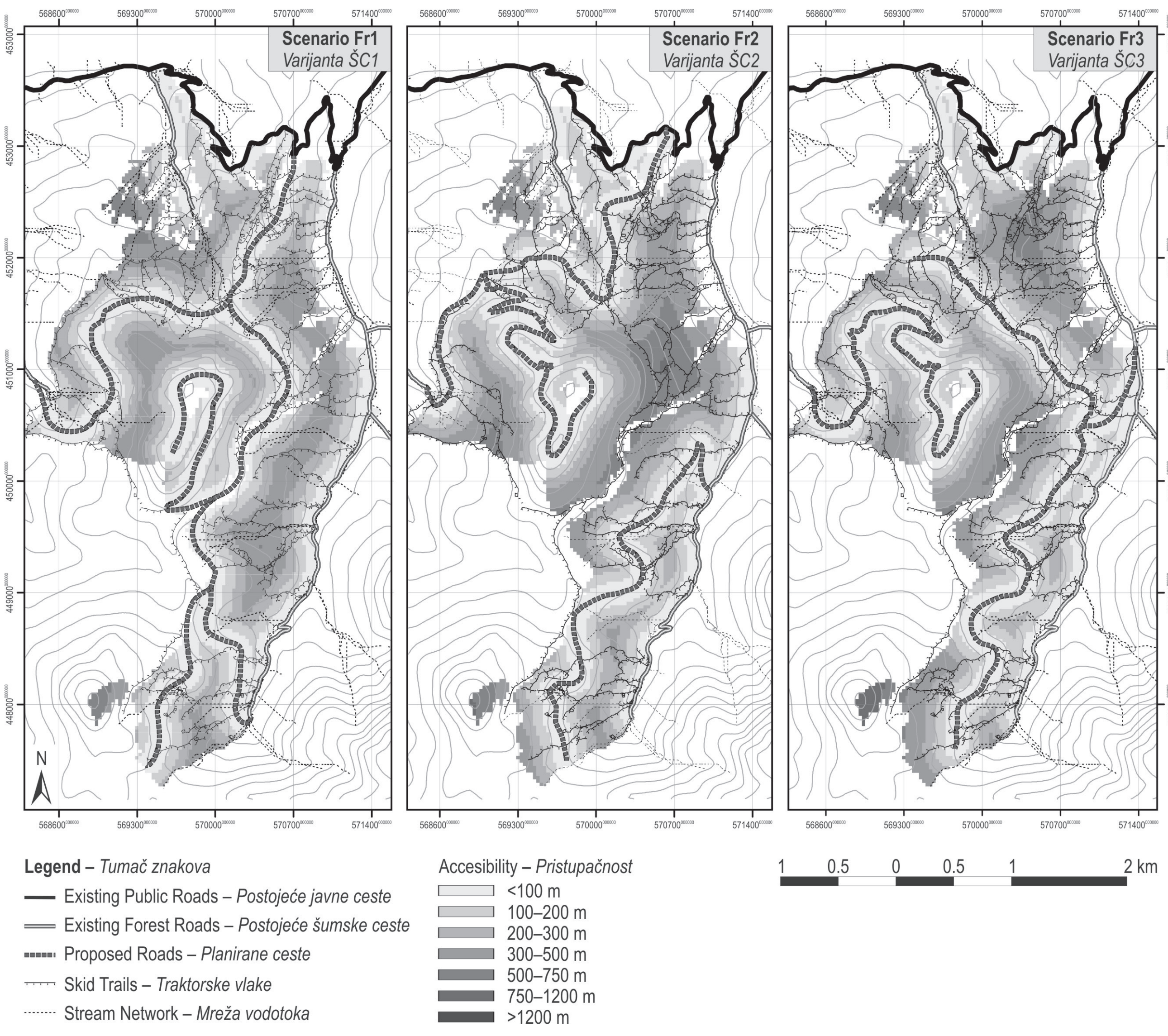

Fig. 4 Infrastructure scenarios proposing new forest roads (FR1–FR3)
Slika 4. *Infrastrukturne varijante predložene novim šumskim cestama (ŠC1–ŠC3)*

Table 3 Structural indices of forest infrastructure before and after planning new roads
Tablica 3. *Strukturni pokazatelji šumske infrastrukture prije i nakon planiranja novih cesta*

Structural indices *Strukturni pokazatelji*	Scenarios – *Varijante*			
	Zero – *Nulta*	FR1 – *ŠC1*	FR2 – *ŠC2*	FR3 – *ŠC3*
Length of road network, m *Duljina mreže cesta*, m	11 719	25 795	25 327	24 501
– out of which new forest roads, m – *od toga novih šumskih cesta*, m	–	14 076	13 608	12 782
Density index of road network, m/ha *Klasična otvorenost mreže cesta*, m/ha	13.0	28.6	28.1	27.2
Road distance, m *Razmak cesta*, m	770	350	356	368
Geometric mean skidding distance SD0, m *Geometrijska srednja udaljenost privlačenja SD0*, m	192	87	89	92
Mean skidding distance (grid 100 x 100), m *Srednja udaljenost privlačenja (mreža točaka 100 x 100)*, m	576	170	191	178
Maximum skidding distance (grid 100 x 100), m *Najveća udaljenost privlačenja ((mreža točaka 100 x 100)*, m	1 402	652	710	826
Actual mean skidding distance, m *Stvarna srednja udaljenost privlačenja*, m	864	255	287	268
Actual maximum skidding distance, m *Stvarna najveća udaljenost privlačenja*, m	2 104	978	1 065	1 238
Length of skid trails network, m *Duljina mreže šumskih vlaka*, m	71 301	67 121	67 349	69 939
Density index of skid trails network, m/ha *Klasična otvorenost mreže traktorskih vlaka*, m/ha	79.0	74.4	74.6	77.5

to state of the art harvesting systems. These issues will be addressed in a further study.

In order to test and validate the conceptual model, a Zero option (current infrastructure conditions) and other three infrastructure scenarios proposing new roads (FR1–FR3) were developed in GIS and considered for the assessment, assuming in all cases current harvesting and skidding means. The alternatives proposing new forest roads were mapped in ESRI® Arc GIS (Fig. 4), based on contour line maps derived from DEM, considering maximum slope grade of the road, terrain steepness and constraint layers developed from cardinal points collected during the field survey. The processes were automated in Model Builder™.

2.8 Cost evaluation of forest road scenarios *Troškovno vrednovanje varijanata šumskih cesta*

Since the proposed roads are intended to serve for low annual timber traffic (<1000 t), they were considered as a low category of secondary forest roads with mixed (fill-cut) cross profiles adapted to natural contour lines, road bed widths of 3.5 m, maximum slope grades of 13% for unloaded trucks and 9% for loaded trucks. According to Enescu (2011), adopting this type of forest road, with a gravel finishing adapted to a low timber traffic volume, could lead to a significant reduction of investment effort (between 20–33%). Therefore, considering Romanian average forest road construction costs of about 100 €/m, the unit construction cost for the study area was estimated to 70 €/m. Maintenance costs were estimated to 2 €/m p.a. for valley roads and 1 €/m p.a. for slope roads. The annuity of forest roads was calculated considering discounted total road construction costs (Pičman and Pentek 1996), for an interest rate of 6.5% and an investment life span of 30 years. Total yearly costs for each scenario were calculated as an algebraic sum of annuity, maintenance costs and discounted earnings from road bed clearance. However, only maintenance costs were

Table 4 Relative openness of the study area
Tablica 4. *Relativna otvorenost istraživanog područja*

Distance to road *Udaljenost do ceste*	Accessible forest area by scenario, % *Pristupačnost šumskomu području po varijantama*, %			
m	Zero – *Nulta*	FR1 – *ŠC1*	FR2 – *ŠC2*	FR3 – *ŠC3*
100	9%	35%	35%	35%
200	17%	62%	58%	62%
300	25%	82%	76%	79%
500	43%	99%	94%	96%
750	64%	100%	100%	99%
1 200	90%	–	–	100%
>1 200	100%	–	–	–

considered in scenario Zero, as the investment has already been paid off (road network older than 30 years).

For each infrastructure scenario, the total harvesting costs were calculated based on unit costs and PSH of each harvesting system. Incomes from timber sales were calculated in accordance with both timber selling procedures, on stump and at road side, based on prices provided by the local forest administration. In the end, the net profit-loss statement for each scenario and each procedure of timber sale was calculated.

3. Results – *Rezultati*

During the assessment process, scenario Zero was compared with the other scenarios (FR1–FR3) based on the specified criteria and sub-criteria weighted by stakeholders' preferences.

3.1 Qualitative assessment of infrastructure scenarios – *Kvalitativna procjena infrastrukturnih varijanata*

In scenario Zero, the access in study area is possible through two valley forest roads and one segment of a public road in total length of 11.72 km, which provide an uneven opening of forest stands. Scenarios FR1–FR3 propose between 12.8 km and 14.1 km of new forest roads (Table 3), improving the accessibility in the studied forest area. The road density increased from 13.0 m/ha (scenario Zero) to 27.2–28.6 m/ha (scenarios FR1–FR3), while the actual mean skidding distance reduced from 864 m (scenario Zero) to about 255–287 m (scenarios FR1–FR3). Thus, good premises for improving productivity and cost efficiency of harvesting systems were created.

A total of 71.3 km of skid trails were mapped during the field survey (scenario Zero). Most of the skid trails were developed on the line of the steepest slope alongside the stream or creek bed, causing massive soil erosion and transport of sediments, a common case being 1.0–1.5 m deep ravines. For scenarios FR1–FR3, the length of skid trails network decreased from 1.4 km to 4.2 km, depending on the case, due to possibilities of partial using of the existing skid trails in planning new roads (Table 3). Hence, the density index of secondary infrastructure ranges between 74.4 m/ha (scenario FR1) and 79.0 m/ha (scenario Zero).

The relative openness of the study area is presented in Table 4. In case of scenario Zero, about 43% of the area is accessible for buffer strip of 500 m from the roads, while approximately 90% is accessible for 1200 m buffer strip. Admittedly, in case of scenarios FR1–FR3, 94% to 99% of the forest area is accessible for a buffer strip of 500 m, while 58% to 62% is accessible for 300 m buffer strip.

3.2 Assessment of harvesting systems – *Procjena sustava pridobivanja drva*

Assessment of harvesting systems was performed in terms of productivity, costs and impact on the environment for each infrastructure scenario.

3.2.1 Productivity and costs – *Produktivnost i troškovi*

Productive system hour (PSH) of harvesting systems has significantly increased in scenarios FR1–FR3 proposing new roads (Fig. 5), when compared to the current infrastructure situation. PSH of the U651 winch tractor increased from 1.9 m^3/h (scenario Zero) to 3.0 m^3/h (scenarios FR1 and FR3), while the PSH of TAF 657 skid-

Table 5 CO_2 emissions from harvesting systems and timber transport
Tablica 5. *Emisija CO_2 od sustava pridobivanja drva i prijevoza drva*

Indicator *Pokazatelj*	Harvesting system *Sustav pridobivanja drva*	Scenario – *Varijanta*			
		Zero – *Nulta*	FR1 – *ŠC1*	FR2 – *ŠC2*	FR3 – *ŠC3*
CO_2 emissions, kg/m^3 Emisija CO_2, kg/m^3	Winch Tractor U651	11.5	7.2	7.4	7.2
	Skidder TAF 657	5.8	3.7	3.8	3.7
	Timber transport – *Prijevoz drva*	1.3	2.8	2.8	2.7

der improved from 7.5 m^3/h (scenario Zero) to 11.7 m^3/h (scenario FR1), triggering also important costs reductions in timber harvesting. Scenario FR1 had the lowest costs of timber extraction for both U651 tractor (8.9 €/m^3) and TAF657 skidder (5.4 €/m^3), when compared to other scenarios (Fig. 6). However, only minor differences were noticed between scenarios FR1–FR3.

3.2.2 Impact on the environment – *Utjecaj na okoliš*

Soil erosion could be limited by reducing the skidding distance and by closing several unnecessary skid trails. The values of dislocated soil due to timber skidding calculated according to Duta (2012) ranged between 47 858 m^3 (scenario FR1) and 50 838 m^3 (scenario Zero).

Table 6 Cost appraisal of infrastructure scenarios
Tablica 6. *Troškovna procjena infrastrukturnih varijanata*

Scenario – *Varijanta*	Zero – *Nulta*	FR1 – *ŠC1*	FR2 – *ŠC2*	FR3 – *ŠC3*
Road network length, m *Duljina mreže cesta*, m	11 719	25 795	25 327	24 501
– out of which new roads, m – *od toga novih cesta*, m	–	14 076	13 608	12 782
Construction cost, €/m *Troškovi izgradnje*, €/m	70			
Total construction costs, € *Ukupni troškovi izgradnje*, €	–	985 320	952 560	894 740
Annual interest rate, % *Godišnja kamatna stopa*, %	6.5			
Life span of investment, years *Životni vijek investicije*, godine	30			
Annuity road construction, € *Renta izgradnje cesta*, €	–	75 453	72 945	68 517
Maintenance costs, € *Troškovi održavanja*, €	23 438	31 655	31 187	30 361
Area of road clearance, ha *Površina oduzeta cestom*, ha	–	16.9	16.3	15.3
Volume from road clearance, m^3 *Volumen oduzet cestom*, m^3	–	5 009.3	4 842.8	4 548.8
Earnings from road bed clearance, € *Zarada od oduzete površine planuma ceste*, €	–	178 376	172 446	161 978
Discounted annual earnings road clearance, € *Godišnja zarada s popustom od oduzete površine ceste*, €	–	13 660	13 205	12 404
TOTAL ROAD COSTS, €/year *UKUPNI TROŠKOVI CESTA*, €/godini	23 438	93 448	90 926	86 474

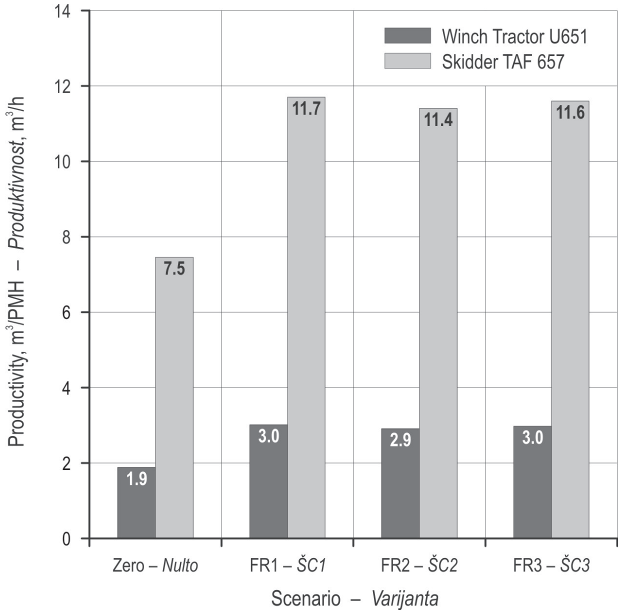

Fig. 5 Timber extraction productivity, by infrastructure scenario
Slika 5. *Produktivnost privlačenja drva po infrastrukturnim varijantama*

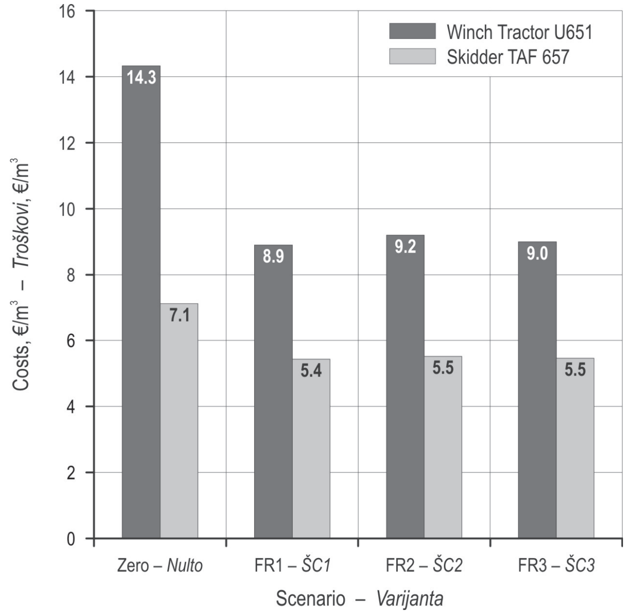

Fig. 6 Timber extraction costs, by infrastructure scenario
Slika 6. *Troškovi privlačenja drva po infrastrukturnim varijantama*

Due to improved infrastructure, a significant reduction in CO_2 emissions from harvesting systems could be achieved in scenarios FR1–FR3 (Table 5), from 11.5 kg CO_2/m^3 (scenario Zero) to 7.2 kg CO_2/m^3 (FR1 and FR3) in the case of the U651 tractor and from 5.8 kg CO_2/m^3 (scenario Zero) to 3.7 kg CO_2/m^3 (FR1 and FR3) in the case of the TAF657 skidder. Regarding CO_2 emissions due to timber transport inside the project area (Table 5), values range between 1.3 kg CO_2/m^3 (scenario Zero) and 2.8 kg CO_2/m^3 (scenario FR1).

3.3 Cost evaluation of forest road scenarios
Troškovno vrednovanje varijanata šumskih cesta

Total road cost is an indicator used in the overall utility evaluation of scenarios, with a relevant significance assigned by stakeholders. Therefore, cost analysis was conducted for all infrastructure scenarios (Table 6). The highest total road costs are required by scenario FR1 (93 448 € p.a.), while scenario Zero has the lowest costs (23 438 € p.a.). When considering only new roads, the lowest road cost scenario is FR3 (86 474 € p.a.).

Net profit-loss statements were calculated for all scenarios and each timber sales procedure (Table 7). First, in the case of timber sales on stump (current practice), the highest net profit was noted for scenario Zero (85 584 € p.a.), which did not involve any construction costs, while the lowest profit was attributed to scenario FR1 (15 574 € p.a.). However, it has to be underlined that all scenarios proposing new roads (FR1–FR3) were profitable. Second, when considering timber sales at the road side, the highest profit was recorded again in scenario Zero (91 300 € p.a.), while the lowest was noted in scenario FR1 (32 756 € p.a.). Scenarios FR1–FR3 proved again to be all profitable (Table 7). In addition, the contribution margin for harvesting operations increased from 1.33 €/m3 (scenario Zero) to 3.99 €/m3 (scenario FR1). Thus, in terms of their overall profit performance, it would be presumably better to change the selling procedure from stumpage to road side.

Provided that the current stumpage sales method is used, investment in new roads (FR1–FR3) would make no sense from the forest owner's point of view, since all profit would represent the forest contractors' profit. Therefore, investing in new forest infrastructure would only make sense if the timber sales procedures were replaced by selling timber at the road side. In this situation, the profits would be to the benefit of the forest owner. Furthermore, subsidies between 50% for private owned forests and 100% for local community forests are available for investing in forest infrastructure through EU Rural Development Programme (MARD 2012). Thus, contribution margin of forest administration could increase from 21.2 €/m^3 (scenario Zero) up to 25.1 €/m^3 (scenario FR1) (Table 7).

Table 7 Profit and loss statement by infrastructure scenarios
Tablica 7. *Dobit i gubitak po infrastrukturnim varijantama*

	Scenario – *Varijanta*			
	Zero – *Nulta*	FR1 – *ŠC1*	FR2 – *ŠC2*	FR3 – *ŠC3*
Timber felling-delimbing-sorting, € *Rušenje, kresanje, razvrstavanje drva, €*	30153			
Timber extraction cost, € *Troškovi privlačenja drva, €*	38 647	27 180	27 835	27 611
Savings timber extraction, € *Uštede pri privlačenju drva, €*	–	11 467	10 812	11 036
Net income timber sales on stump, € *Neto prihod od prodaje drva na panju, €*	109 022			
Income timber sales at the road side, € *Prihodi od prodaje privučenoga drva, €*	183 537			
Net income timber sales at the road side, € *Neto prihod od prodaje privučenoga drva, €*	114 738	126 204	125 549	125 773
Total road costs, €/year *Ukupni troškovi cesta,* €/godini	–23 438	–93 448	–90 926	–86 474
Total road costs (€/year) with EU incentives *Ukupni troškovi cesta (€/godini) s poticajima EU-a*	–23 438	–17 995	–17 981	–17 957
NET PROFIT-LOSS STATEMENT – *NETO DOBIT I GUBITAK*				
Timber sales on stump, €/year *Prodaja drva na panju,* €/godini	85 584	15 574	18 097	22 549
Timber sales at road side, €/year *Prodaja privučenoga drva,* €/godini	91 300	32 756	34 624	39 300
Timber sales at road side and EU incentives, €/year *Prodaja privučenoga drva i poticaji EU-a,* €/godini	91 300	108 209	107 568	107 817
TOTAL CONTTRIBUTION MARGIN FOR FOREST ADMINISTRATION *UKUPNA KONTRIBUCIJSKA MARŽA ZA UŠP*				
Timber sales on stump, €/m^3 *Prodaja drva na panju,* €/m^3	19.87	3.62	4.20	5.23
Timber sales at road side, €/m^3 *Prodaja privučenoga drva,* €/m^3	21.20	7.60	8.04	9.12
Timber sales at road side and EU incentives, €/m^3 *Prodaja privučenoga drva i poticaji EU-a,* €/m^3	21.20	25.12	24.97	25.03

3.4 Utility analysis and decision making – *Analiza korisnosti i odlučivanje*

Based on stakeholders' preferences regarding the importance of defined criteria and sub-criteria, the overall utility value of each scenario was calculated (Table 8). Stakeholders' consultation showed that the most important sub-criteria were: accessibility for performing silvicultural operations (20%), protection of ecologically important areas (14%) and road construction costs (11%). The least important one was the accessibility for touristic, local or cultural points of interest (1%). According to MAUT, the best alternative is the one with the highest score in total. With a total score of 0.682, scenario FR3 is the alternative that would best satisfy stakeholders' preferences and thus it would be recommended for implementation (Fig. 7).

The decision support tool for evaluating forest road alternatives presented in this study was tested and

Table 8 Multiple utility analysis of infrastructure scenarios
Tablica 8. *Višestruka analiza korisnosti infrastrukturnih varijanata*

Final scoring of alternatives – *Konačno bodovanje varijanata*										
Code *Šifra*	Criteria *Kriterij*	Weight *Važnost*	SCENARIO – *Varijanta*							
			Zero – *Nulta*		FR1 – *ŠC1*		FR2 – *ŠC2*		FR3 – *ŠC3*	
			UUV	WUV	UUV	WUV	UUV	WUV	UUV	WUV
A1	Neighbors independence *Neovisnost o susjedstvu*	8%	1.0	0.079	1.0	0.079	1.0	0.079	1.0	0.079
A2	Accessibility for forest operations *Pristupačnost za šumske poslove*	20%	0.0	0.000	1.0	0.201	0.9	0.179	1.0	0.192
A3	Accessibility for game management *Pristupačnost za lovno gospodarenje*	4%	0.0	0.000	1.0	0.045	0.9	0.041	0.8	0.034
A4	Loss of productive land (road clearance) *Gubitak šumskoga zemljišta (širina ceste)*	5%	1.0	0.049	0.0	0.000	0.0	0.002	0.1	0.004
B1	Construction costs *Troškovi gradnje*	11%	1.0	0.110	0.6	0.067	0.7	0.074	0.8	0.086
B2	Maintenance costs *Troškovi održavanja*	7%	1.0	0.070	0.0	0.000	0.1	0.004	0.2	0.011
B3	Harvesting costs *Troškovi pridobivanja drva*	8%	0.0	0.000	1.0	0.078	0.9	0.073	1.0	0.075
C1	Protection of ecologically valuable areas *Zaštita ekološki vrijednih područja*	14%	1.0	0.143	0.0	0.000	0.2	0.027	0.2	0.027
C2	CO_2 emissions – *Emisija CO_2*	5%	0.0	0.000	0.9	0.043	0.8	0.040	1.0	0.047
C3	Visual disturbance due to Curves/Intersections *Vizualni poremećaj zbog krivina i raskrižja*	6%	1.0	0.057	0.3	0.014	0.0	0.000	0.3	0.019
D1	Fewer accidents with personal injuries *Manji broj nesreća s osobnim ozljedama*	3%	0.0	0.000	0.9	0.025	0.7	0.021	1.0	0.029
D2	Risks of soil erosions and/or landslides *Rizik od erozije tla ili klizišta*	3%	0.0	0.000	1.0	0.026	0.6	0.017	0.7	0.018
D3	Accessibility for touristic/local/cultural interest *Pristupačnost za turističke, lokalne, kulturne interese*	1%	0.0	0.000	1.0	0.026	0.8	0.017	0.8	0.018
D4	Accessibility in case of forest fires *Pristupačnost u slučaju požara*	3%	0.0	0.000	1.0	0.013	0.9	0.011	1.0	0.010
D5	Accessibility in case of wind-throws/snow *Pristupačnost u slučaju vjetroizvala i snjegoloma*	2%	0.0	0.000	1.0	0.033	0.9	0.030	1.0	0.033
Total score – *Ukupni rezultat*		100%	6.0	0.507	10.6	0.651	9.5	0.614	10.6	0.682

* UUV - unweight utility values – *neponderirane vrijednosti korisnosti;* WUV – weighted utility values – *ponderirane vrijednosti korisnosti*

validated based on a participatory process. Considering multiple stakeholders' interests, all scenarios proposing new roads (FR1–FR3) performed better in overall terms than scenario Zero. Based only on normalized utility values of each sub-criterion (before weighting each sub-criterion with stakeholders' preferences), the total scoring showed that scenarios FR1 and FR3 were ranked equal first (Table 8). When stakeholders' preferences were considered, FR3 was the best performing scenario. Thus, it could be concluded that stakeholders' preferences do have significant importance. Therefore, sensitive analyses were conducted in order to show how changes in stakeholders' preferences for specific criteria or sub-criteria could affect the final

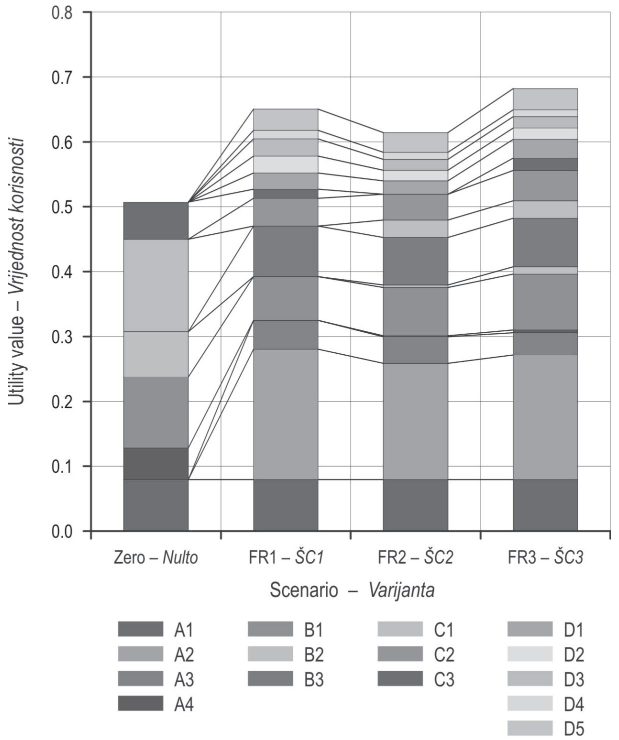

Fig. 7 Final score of scenarios after multiple utility analyses, based on sub-criteria A1–D5

Slika 7. *Konačni rezultati varijanata nakon višestruke analize korisnosti, temeljene na potkriterijima A1–D5*

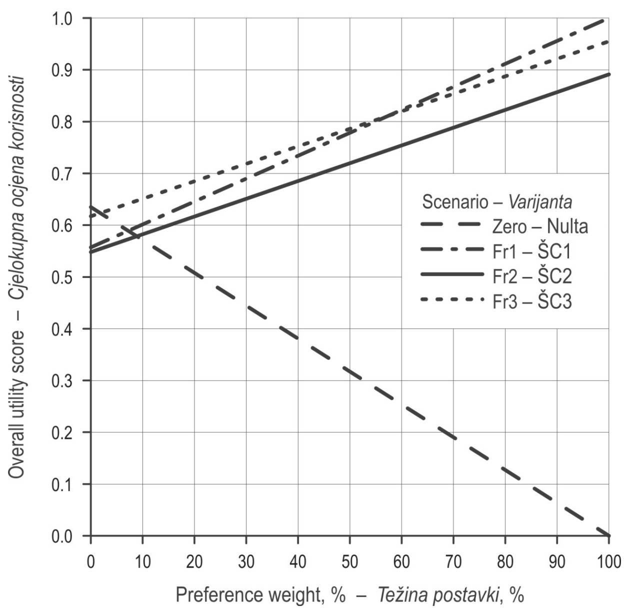

Fig. 8 Sensitive analysis regarding performance of accessibility for forest operations sub-criterion

Slika 8. *Osjetljiva analiza o djelovanju potkriterija pristupačnost za šumske poslove*

results. As an example, the sensitivity analysis regarding accessibility for forest operations sub-criterion was performed. Fig. 8 shows that scenario FR3 would perform best for preference weights up to 60% given to this sub-criterion. If the preference weight were above 60%, than scenario FR1 would be recommended for implementation. Regardless the preference given by the stakeholders to this sub-criterion, scenario Zero had the lowest score. Similarly, sensitivity analyses could be performed for all other criteria and sub-criteria.

4. Discussions and conclusions – *Rasprava i zaključci*

The aim of this study was to develop a decision support tool for evaluating different forest road options before technical design, using a participatory approach and multiple criteria analyses. Based on clearly defined criteria and sub-criteria, qualitative and quantitative assessments of forest infrastructure scenarios were performed. The conceptual model of the decision support tool showed a clear flow of processes and how the evaluation of forest road options could be done. The main processes refer to locating new roads, assessment of productivity and appraisal of cost efficiency in timber extraction, evaluation of impact on the environment and finally, the utility analysis of infrastructure scenarios. The model was tested and validated in a mountainous forest located in Romania. A suitable road variant based on stakeholders' preferences was recommended for implementation. Thus, the importance of the preliminary planning and assessment phase in forest road engineering was highlighted.

The multiple attribute utility theory (MAUT) proved to be an appropriate tool for evaluating forest road alternatives because, among others, it also allowed sensitivity analyses regarding the importance of stakeholders' preferences in the final score of alternatives. In comparison to the analytic hierarchy process (AHP) used by Coulter (2004), which is a more complex tool requiring expert judgments based on pairwise comparisons, MAUT was preferred in this study for its simplicity in use and its proven practicality in the development of decision support tools in the forestry sector (Lexer et al. 2005; Kangas et al. 2008). In addition, this study continued and extended the work of Zarojanu (2006; 2007), comprehensively and soundly addressing the economic, ecological and social aspects in selecting the most suitable forest road option, as recommended in the literature by Dürrstein (1998) and Heinimann (1998). Thus, this model proved its utility for supporting decision making in forest road engineering and could be used in other regions with similar topographic, forest site and social-cultural conditions. The decision support tool presented in this study could be improved by further process automation and by extending it with the assessment of the impact of new harvesting systems that could be introduced in the study area in the overall utility analysis of the infrastructure scenarios.

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Sažetak

Integracijski alat za odlučivanje pri procjeni varijanata šumskih cesta u planinskom području Rumunjske

Razuman je razvoj šumske infrastrukture okosnica za održivo gospodarenje šumama. Međutim, današnje planiranje šumskih prometnica mora ispuniti više sukobljenih ciljeva, što nije jednostavan zadatak. Model temeljen na GIS-u razvijen je za potporu odlučivanja u inženjeringu šumskih cesta. Alat dopušta procjenu šumskih infrastrukturnih varijanata na temelju analize različitih kriterija s obzirom na interese sudionika, gospodarske, ekološke i socijalne aspekte. Prvo, problem pri odlučivanju jasno je strukturiran, a zatim su ponderirani kriteriji i potkriteriji. Nakon toga su definirane varijante šumskih cesta te su izvedene kvantitativne i kvalitativne procjene infrastrukture i sustava pridobivanja drva. Na kraju je provedena analiza korisnosti za svaku varijantu; varijanta šumske ceste s najvišom ocjenom korisnosti odabrana je kao najprikladnije rješenje za provedbu. Model je provjeren i potvrđen u planinskom šumskom području županije Braşov u Rumunjskoj. Šumsko se područje nalazi na nadmorskoj visini od 900 do 1600 m. Jedna petina promatranoga šumskoga područja nalazi se na blagim padinama (<20 %), dok se oko 10 % nalazi na strmom terenu (>55 %). Postignuto je smanjenje srednje udaljenosti privlačenja s 864 m na 255 – 268 m, što dovodi do povećanja produktivnosti privlačenja sa 7,5 m^3/h na 11,7 m^3/h te do povećanja kontribucijske marže s 21,2 €/m^3 na 25,1 €/m^3. Unapređenje šumske infrastrukture smanjuje emisiju CO_2 prilikom privlačenja drva i transporta s 8,52 kg/m^3 na 7,3 kg/m^3. Ovo istraživanje pokazuje kako se multikriterijska analiza korisnosti može upotrijebiti u procjeni različitih varijanata šumskih cesta temeljenih na zajedničkom pristupu. Multikriterijska analiza korisnosti (MAUT) pokazala se kao prikladno sredstvo za procjenu varijanata šumske ceste jer, među ostalim, uključuje analizu osjetljivosti s obzirom na preferencije sudionika u konačni rezultat varijanata. Alat za podršku odlučivanju prikazan u ovom istraživanju može biti poboljšan daljnjim procesom automatizacije i njegovim proširenjem za nove sustave privlačenja koji bi mogli biti uključeni u područje istraživanja.

Ključne riječi: šumske ceste, multikriterijsko odlučivanje, analiza korisnosti, alat za odlučivanje, zajednički pristup

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