Spatial Multi-Criteria Decision Process to Define Maintenance Priorities of Forest Road Network: an Application in the Italian Alpine Region

Marco Pellegrini, Stefano Grigolato, Raffaele Cavalli

Abstract – Nacrtak

The combination of GIS tools and Analytic Hierarchy Process (AHP) techniques is used to develop a Decision Support System to rank the maintenance priorities of a forest road network according to the actual conditions and needs. The decision-making process is divided into 4 stages. The first stage fixes the objectives of the analysis as the minimization of the sediment production from road surface and the maximization of the social value of the road. The second stage defines the hierarchical structure of the decision problem. At this stage the set of factors (criteria) to maximize each objective and the evaluation methods are defined. At the third stage AHP analysis is applied using a specific application running on ArcGIS, to calculate the evaluation layer that represents the importance of each road according to the set objectives. The values of the evaluation layer are used at the fourth stage to rank the maintenance interventions according to the given benefit. The methodology has been tested in a forest road network with an extension of 107.8 km including in the analysis the real budget constraints and maintenance costs.

The results show that the integrated use of GIS and AHP analysis represents a valuable tool to rate the importance of the forest road network for the management of a mountain territory and to define priorities among maintenance operations of the road network, in order to maximize the overall benefit with limited economic resources.

Keywords: forest road maintenance, maintenance cost, AHP, GIS, Decision Support System

1. Introduction – *Uvod*

Routine road maintenance is vital to keep a forest road system serviceable and to maintain the proper working of its drainage system. Many studies show how a well-maintained road can be protected from rapid deterioration, minimizing sediment production (Thompson et al. 2010) and improving the trafficability with a reduction of trucking costs (Feng and Douglas 1993; Talbot and Nitteberg 2011). Each year, a consistent amount of money is spent to upgrade and maintain forest road networks. In order to optimize the use of limited funds, it is of primary importance to set investment priorities while meeting management and environmental goals. The resulting task is complex because of the many aspects involved in forest road management, including the natural environment and the socio-economic context in which the road network is located. For that reason, the management of forest road networks needs methods to integrate multiple objectives and set priorities across these different goals.

Existing studies generally focus on a single aspect in order to better understand the conditions of the road network and the processes related to this road. The Washington Department of Natural Resources and Boise Corporation has created an empirically based model (SEDMODL) used to estimate road-related sediment production and transport to streams (Dubè et al. 2004). Potočnik et al. (2006) investigate a traffic management strategy in the preserved forest area of the Pokljuka highland (Slovenia) considering the touristic importance of the roads. Hruza and Vyskot (2010) evaluate a forest road network according to the social-recreation value in order to define the optimal path for touristic trails.

Spatial multi criteria decision techniques provide tools for aggregating the geographical data and the decision-makers preferences into unidimensional value or utility of alternative decisions, combining a set of criteria to achieve a single composite basis for a decision according to a specific objective (Malczewski 1999).

Although there is a variety of techniques for the determination of the weight of a given set of criteria, one of the most promising seems to be the pairwise comparisons developed by Saaty (1980) in the context of a decision-making process known as the Analytical Hierarchy Process (AHP). In the pairwise comparison method, the decision-maker is asked to give the relative importance to the criteria by comparing them two by two. Schmoldt et al. (2001) describes the basis of the application of the AHP in natural resource and environmental decision-making.

The use of AHP appears to have the potential to help managing the existing road systems where research has not yet uncovered quantifiable relationships between cause and effect, meaning that the synthesis of road inventory data to set investment priorities should depend in part on professional judgment. According to this idea, Coulter et al. (2006) developed a maintenance priority definition methodology that uses AHP analysis in order to minimize the environmental impact to soil and water resources from forest roads. Shiba (1995) used an AHP based approach to improve the development strategy of road network in mountainous areas of Japan considering complex socio-economic problems. AHP analysis and GIS tools have been recently applied to evaluate the needs of forest roads in a mountainous area of Italy (Cavalli et al. 2010) and to evaluate new forest road location alternatives (Abdi et al. 2009).

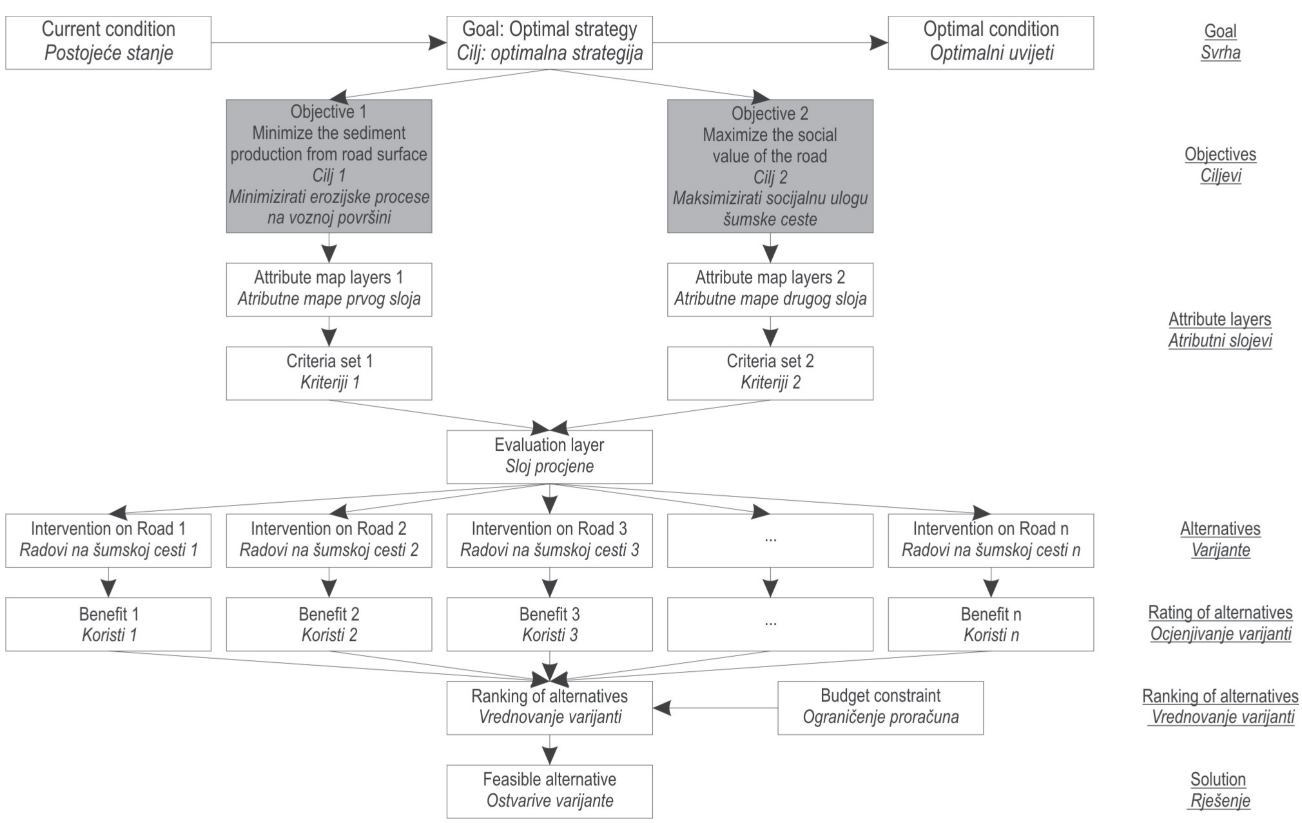

Fig. 1 General layout of the analysis
***Slika 1.** Izgled analize*

Table 1 Considered criteria and relative evaluation methods
***Tablica 1**. Kriteriji i relativne metode procjene*

Criteria – *Kriteriji*	Evaluation Methods – *Metode procjene*
Objective 1 – Erosion risk – *Cilj 1 – Rizik od erozije*	
Road gradient (*i*GRADE) – *Uzdužni nagib ceste*	GIS analysis (Model based on contour line) – *Analiza pomoću GIS-a (model temeljen na slojničkim kartama)*
Surface condition (*i*COND) – *Stanje vozne površine*	Visual evaluation (field survey) – *Vizualna procjena (terensko istraživanje)*
Drainage system (*i*DRAIN) – *Elementi sustava odvodnje*	Visual evaluation (field survey) – *Vizualna procjena (terensko istraživanje)*
Traffic (*i*TRAFFIC) – *Prometno opterećenje*	GIS analysis (based on Network analysis) – *Analiza pomoću GIS-a (model temeljen na slojničkim kartama)*
Location of the road (*i*SLOPE) – *Položaj šumske ceste*	GIS analysis (based on Digital Terrain Model) – *Analiza pomoću GIS-a (temeljena na digitalnom modelu terena)*
Objective 2 – Social value – *Cilj 2 – Socijalna vrijednost*	
Touristic importance (*i*TOUR) – *Turistička uloga*	GIS analysis (access to touristic sites) – *Analiza pomoću GIS-a (pristupačnost turističkim znamenitostima)*
Farming importance (*i*FARM) – *Poljoprivredna uloga*	GIS analysis (access to agricultural/farming sites) *Analiza pomoću GIS-a (pristupačnost poljoprivrednim gospodarstvima/farmama)*
Productive importance (*i*PROD) – *Gospodarska uloga*	GIS analysis – *Analiza pomoću GIS-a*
Operative class (*i*OPER) – *Operativni razred*	Visual evaluation (field survey) – *Vizualna procjena (terensko istraživanje)*

The present study combines GIS tools and AHP techniques to rank the maintenance priorities in a forest road network. In particular, the proposed methodology integrates the evaluation of the risk of erosion from road surface and the evaluation of the multifunctionality of forest roads, resulting particularly suitable for areas where the management of the roads have to consider many different functions. The result of the analysis is applied to support the use of the economic resources for the maintenance of a forest road network in the Italian Alpine region.

2. Material and methods – *Materijal i metode*

2.1 Analysis structure – *Struktura analize*

Any decision-making process begins with the recognition of decision problems. A spatial decision problem is the difference between the desired and the existing state of a real-world geographical system (Malczewski 1999). Simon (1960) suggests that any decision-making process can be structured in three major phases: intelligence (is there a problem or an opportunity for change?), design (what are the alternatives?), choice (which alternative is better?). The procedure passes through the evaluation of the actual status of a forest road network and the actual maintenance strategies to search for the improving elements (Fig. 1). The production of sediment from the gravel road surfaces represents one of the most frequent and hazardous processes directly connected with the presence and maintenance of the forest road network. The minimization of this process is directly related to the correct execution of the maintenance interventions and has been considered as the first objective. The other leading elements in determining maintenance interventions are the type and level of use of the forest road. Following a multi-functional approach, the maximization of the social values has been considered as second objective in the priorities definition.

The set of criteria and the hierarchical structure of the decision problem have been developed through the examination of the relevant literature regarding the analyzed aspect and through the opinion of experts and stakeholders.

2.2 Criteria evaluation – *Kriteriji procjene*

Minimization of the risk of sediment production from forest road surface (Objective 1): sediment can be eroded from all road features but road surface erosion is generally the dominant source of sediment (Ramos-Scharron and MacDonald 2005). A recent review paper on surface erosion and sediment delivery model for unsealed road (Fu et al. 2010) effectively describes the main factors highlighted in literature. These factors include rainfall intensity and duration, snowfall, characteristic of road surface and used materials, road slope, traffic, construction standards and level of maintenance (MacDonald and Coe 2008). The gradient, or slope, of a road segment influences the erosion rate. Water flows down steeper road segments more quickly, resulting in a greater erosive power and in a higher shear stress (Bilby et al. 1989; Elliot and Tysdal 1999; Luce and Black 1999a). The width of the road and the extent of traffic on a road both influence the amount of erosion produced from the road surface. Researches by Reid and Dunne (1984); Grayson et al. (1993); Luce and Black (1999b); Ziegler et al. (2001a); Sheridan and Noske (2007) were specifically aimed at determining the effects of traffic on road erosion. All of these studies showed increasing erosion rates with increased traffic use. According to the literature, the set of criteria considered for Objective 1 are: road gradient, surface condition, presence of drainage structure, level of traffic and location of the road on the hill-slope (Table 1).

Maximization of the social value of the road network (Objective 2): to evaluate the social value, the different functions that each road can perform have been considered. After discussion with stakeholders of the studied area, we considered the following functions: touristic importance (access to important tourist sites), farming importance (access to farming activities), productive importance (access to productive forests) and operative class (actual constructive parameters of the road and ease of transit) (Table 1). Once the hierarchical structure of objectives and attributes has been established, each criterion can be represented as a raster map layer in the GIS database. Information about surface condition, presence of drainage structures, operative class, touristic and farming importance, were collected during the field surveys and reported as attributes to the layer representing the forest road network. To determine road gradient, hill-slope and level of traffic in a representative layer, three semi-automated analysis procedures have been developed using geo-processing tool for surface analysis and Network Analysis techniques. The analyses have been supported by ArcGIS 10 (ESRI 2011) and ModelBuilder interface. In all the cases, the inputs needed to run the models are the digital terrain model (DTM) and forest type regional map.

Multi-criteria decision analysis requires that the values contained in the various criterion map layers be transformable to comparable units. For this reason all of the data have been converted into standardized values using the maximum score procedures.

$$X'_{ij} = \frac{X_{ij}}{X_{max}} \tag{1}$$

Where:

X'_{ij} the standardized score for the i^{th} object (alternative),

j^{th} attribute and x_{ij} is the raw score and x_{max} is the maximum score for the j^{th} attribute.

The scale of standardized scores range from 0 to 1000, where higher overall score values indicate greater benefit. A pairwise comparison matrix was completed according to expert judgment and opinions of different people representing local perceptions regarding the importance of the different criteria. The following AHP analysis was supported by the use of a specific application (AHP 1.1 – Decision support tools for ArcGIS) for multi-criteria analysis based on pairwise comparison (Marinoni 2004a; Marinoni 2004b).

2.3 Evaluation of road conditions and maintenance costs – *Procjena stanja i troškovi održavanja šumskih cesta*

The basis for the development of a road maintenance plan is a thorough understanding of the road system, its characteristics, and its needs. This is accomplished by establishing and maintaining an intensive inventory of the road system. The inventory has to provide the information necessary for identifying and prioritizing the required maintenance such as categorization of roads, identification of drainage structures and their state and information related to the condition of the road surface (Cavalli et al. 2010).

The most important characteristics of each forest road have been collected and organized in a geodatabase structure. Road survey information included road width, surface type, surface condition, traffic limitation, presence and efficiency of drainage structures, functional and operative classification. To estimate the maintenance needs, the drainage system and surface condition were visually evaluated and rated as reported in Table 2.

The cross-drain culvert spacing (CS) is calculated in relation to the road gradient (slope, in %) using the following formula reported in the forest road manual (Oregon Department of Forestry 2000):

$$CS = 800/\text{slope} \tag{2}$$

The number of cross-drain structures to be installed is then calculated considering the length of

Table 2 Adopted code in the evaluation of the road conditions
Tablica 2. *Procjena stanja šumskih cesta*

Drainage structure *Stanje odvodnih elemenata*		Rate *Ocjena*	Operation *Zahvat*
Present and functional *Postojeća funkcionalna*	The drainage system does not need maintenance *Elementi sustava odvodnje koji ne trebaju održavanje*	0	No – *Bez*
Present and not functional *Postojeća nefunkcionalna*	The drainage system needs maintenance immediately *Elementi sustava odvodnje koji trebaju hitnu sanaciju*	1	A
Missing *Nedostaje*	The drainage system is missing *Nedostaju elementi sustava odvodnje*	2	D
Surface condition *Stanje gornjega ustroja*			
Regular *Normalno*	The road surface is functional and the trafficability is efficient. Road fits perfectly its preeminent function. No evident sign of erosion or potholes *Vozna je površina funkcionalna, a prometnost učinkovita. Cesta savršeno ispunjava zadanu funkciju. Nema očitih znakova erozije ni udarnih rupa*	1	No – *Bez*
Partially damaged *Djelomično oštećeno*	Minor rilling is present on the surface. The condition slightly affects the trafficability. Potholes and erosion process are present but not very evident. The road needs regular surface maintenance intervention *Na voznoj su površini prisutne vododerine koje u manjoj mjeri utječu na prometnost. Udarne su rupe i erozija prisutne, ali nisu jako uočljive. Na cesti se trebaju izvoditi zahvati obuhvaćeni redovitim održavanjem*	2	B
Damaged *Oštećeno*	Severe rilling is present on the surface Trafficability is affected and sometimes the road cannot perform its function. The road needs an extraregular intervention of surface maintenance *Na voznoj su površini prisutne velike vovoderine koje utječu na prometnost, a cesta ne ispunjavaju svoju funkciju u potpunosti* *Na cesti se trebaju izvoditi zahvati obuhvaćeni periodičnim održavanjem*	3	C

each road segment, where drainage structures are missing. The result has to be considered only as an indication of how detailed placement of cross-drainage culverts has to be evaluated taking into account the specific conditions of individual sites. The evaluation of maintenance needs is conducted to understand the current state of the forest road network and the gap between the actual and optimal conditions that represents the area in which the definition of the best maintenance strategy will be defined.

The result of the survey is a map representing all the maintenance operations needed to upgrade the forest road network. The sum of the maintenance interventions on each road section (node to node) represents one possible alternative in the ranking procedures.

Finally four types of possible maintenance operations were defined. The mean cost for each type of operation was determined through project analysis (Table 3) and the derived mean cost has been used to calculate the economic resources needed to complete each intervention (alternatives) on the forest road network.

3. Results – *Rezultati*

The methodology was applied to a test area of 3991 ha located in the »Altopiano dei Sette Comuni« in the North-Eastern part of Italy (latitude N of 45.56–45.52 longitude E of 11.23–11.28). The region is mainly covered by Norway Spruce (*Picea abies*) and Beech (*Fagus sylvatica*) forests. The area represents a meaningful case study because the forest road network has to solve many different preeminent functions.

The recreational function is primarily a consequence of the presence of many historical sites related to the First World War and scenic hiking trails in the area. The silvicultural function is also important as

Table 3 Types of road maintenance operations performed and related costs
Tablica 3. *Vrste i relativni troškovi izvođenih radova pri održavanju šumskih cesta*

Operation type *Vrsta radova*	Operational details *Detalji pri izvođenju pojedine vrste radova*	Cost *Trošak*
A, Drainage structure cleaning *A, čišćenje elemenata odvodnje*	2 operators *2 radnika*	1.10 € DS^{-1}*
B, Regular surface management**: addition of crushed aggregate and consolidation *B, redovito održavanje**: dovoz rasutoga materijala i ugradnja*	1 Tractor with grader – *Traktor s grejderskom daskom* 1 Truck for gravel transportation – *Kamion za transport šljunka* 3 operators – *3 radnika*	1.21 € m^{-1}
C, Extraordinary surface management** *C, periodično održavanje***	1 Tractor with grader – *Traktor s grejderskom daskom* 1 Truck for gravel transportation – *Kamion za transport šljunka* Excavator – *Bager* 3 operators – *3 radnika*	6.32 € m^{-1}
D, Drainage structure installation *D, Ugradnja odvodnih elemenata*	Excavator – *Bager* 2 operators – *2 radnika* Materials – *Materijal*	52 € DS^{-1}*

* DS: drainage structure (standard length 5 m) – **DS: odvodni elementi (standardna duljina 5 m)*
** standard road width 3.50 m – ***Standardna širina ceste 3,50 m*

expected due to the presence of productive forest. Finally, the forest road network has to guarantee access for the farming activities. The length of the primary forest road network inside the area is 107.8 km (of which 80 km are gravel roads) with a density of 26 m/ha. Lastly, 68.1 km (65.4%) of the road network is accessible without restriction (public roads) while 39.7 (34.6%) presents restrictions.

3.1 Definition of alternatives and maintenance cost analysis – *Određivanje varijanti i troškovna analiza održavanja*

The field survey shows that 12% of the total extension of the forest road network is in good conditions, while the remaining 88% requires maintenance interventions. 390 maintenance interventions have been identified among a total of 44 road segments (alternatives). The majority of maintenance operations involve the improvement of the drainage system, including the installation of new structures (53% of the total extension) and cleaning of the existing ones (23%). Surface maintenance is required on 11 road segments (20%).

The total investment to complete the maintenance of the project was estimated to 68 297 €. Table 4 shows the number of needed interventions and the estimated budget to complete all the interventions. During the observed period, 2008–2010, the management authorities carried out interventions on 27 forest roads with-

Table 4 Required maintenance interventions and estimated costs
Tablica 4. *Potrebni radovi pri održavanju i procijenjeni troškovi*

Operation type – *Vrsta radova*	Interventions, n *Učestalost izvođenja pojedine vrste radova,* n	Total cost, € *Ukupni troškovi*, €
A (Drainage structure cleaning) – *A (Čišćenje elemenata sustava odvodnje)*	98	107.8
B (Regular surface management) – *B (Redovito održavanje)*	6	10 350
C (Extraordinary surface management) – *C (Periodično održavanje)*	5	34 617
D (Drainage structure installation) – *D (Ugradnja odvodnih elemenata)*	281	14 612
TOTAL – *UKUPNO*	390	68 297

Table 5 Criteria weights as resulted from pairwise grid evaluation
Tablica 5. *Procjena kriterija udvojenoga vrednovanja*

Objective 1 – Erosion risk – *Cilj 1 – Rizik od erozije*		Objective 2 – Social value – *Cilj 2 – Socijalna vrijednost*	
Sub-criteria – Potkriterij	Weight – Težina	Sub-criteria – Potkriterij	Weight – Težina
*i*GRADE	0.5661	*i*TOUR	0.4236
*I*DRAIN	0.2012	*i*OPER	0.2903
*I*COND	0.1319	*i*FARM	0.1745
*i*SLOPE	0.1007	*i*PROD	0.1114
Consistency ratio* (CR): 0.0434 *Faktor dosljednosti** (CR): 0,0434		Consistency ratio* (CR): 0.0750 *Faktor dosljednosti** (CR): 0,0750	

*Revision of preference values is recommended if CR > 0.1
**Preporučuje se preispitivanje vrijednosti ako je CR > 0,1*

Table 6 Attribute tables of the features of forest road network
Tablica 6. *Atributna tablica mreže šumskih cesta i njihovih svojstava*

Rank *Rang*	Road Id *Koristi od šumske ceste*	Sed_Risk *Zaštitna vrijednost*	Soc_Val *Socijalna vrijednost*	Eq_Val *Srednja vrijednost*	C1	C2	C3	Tot_Cost *Ukupni trošak*
1	50	391	627	509	312	0	0	312
2	35	259	663	461	312	0	1 388	1 702
3	37	230	649	440	104	0	0	104
4	41	200	573	387	312	918	802	2 032
5	58	253	484	368	104	834	0	938
6	40	391	302	347	624	0	7 256	7 880
7	30	403	198	339	728	0	7 713	8 441
8	38	307	288	305	1 976	0	1 693	3 669
9	53	406	442	302	936	0	7 565	8 501
10	28	309	259	298	104	0	0	104
11	42	154	215	281	104	0	0	104

in the area for a total of 30.7 km of roads maintained, with the total expense of 87 000 €. According to this, the assumed annual budget for regular maintenance equals 29 000 € (budget constraint).

3.2 Rating and ranking of alternatives
Ocjenjivanje i vrednovanje varijanti

Table 5 shows the output weights for the different factors taken into consideration, after the AHP pairwise grid evaluation.

Application of the spatial AHP analysis led to the creation of the two raster layers that represent the benefit score referred to the relative objective for each cell of the road surface. The combination of the two layers at the highest level of the AHP analysis, produced the final evaluation layer that represented the overall benefit score for each cell. The evaluation layer maps made as a result of the application of the AHP process are presented in Fig. 2.

Through the use of a zonal statistic tool, the cell values on the evaluation layer were summarized within the forest road network features and the statistics relative to the benefit value of each road have been calculated. Table 6 is an example of the attribute table

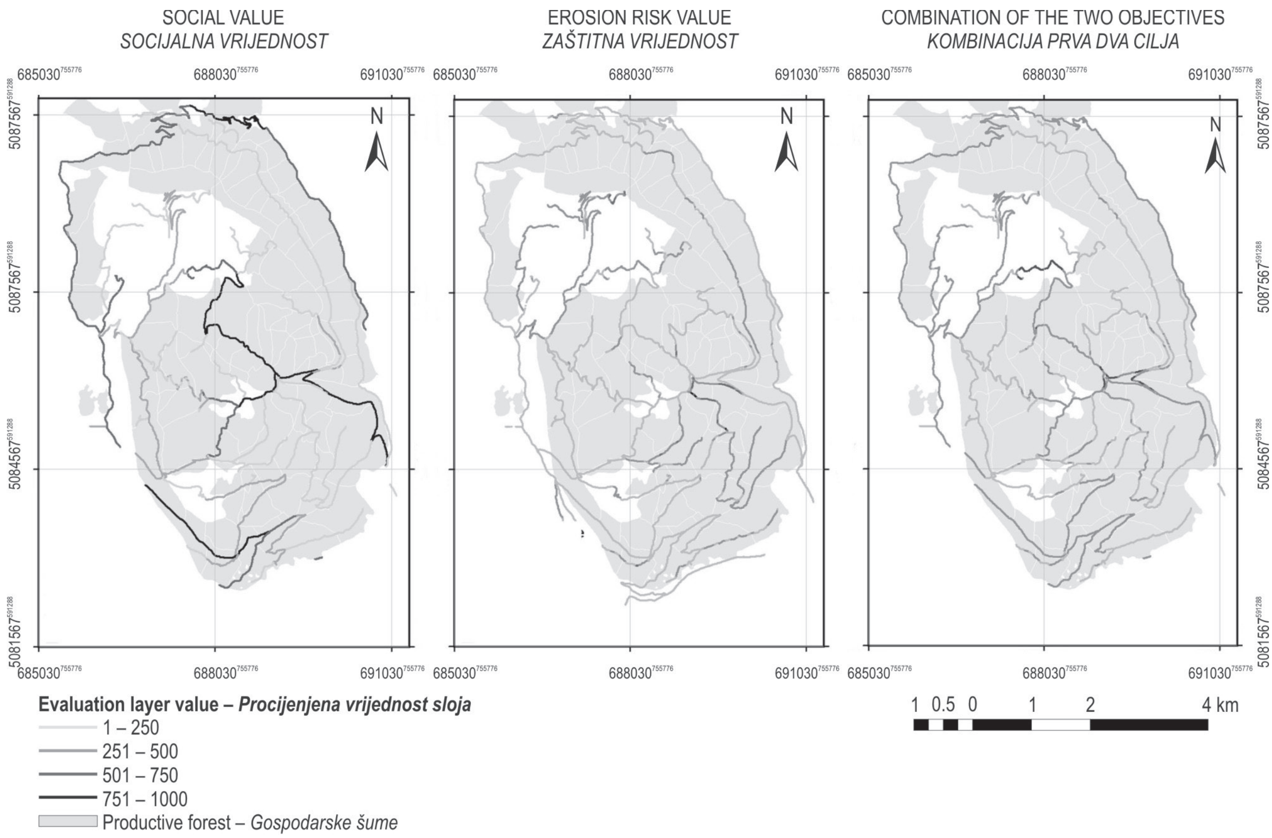

Fig. 2 Maps representing the evaluation layers considering different objectives

Slika 2. *Karte predstavljaju procijenjene slojeve s obzirom na različite ciljeve*

of the features of forest road network after the application of the AHP analysis. Roads (ROAD ID) are ranked according to their benefit value, where SED_RISK represents the risk value of sediment production from the road surface, SOC_VAL represents the social value of the road and EQ_VAL represents the combination of the two values (evaluation layer). C1, C2 and C3 represent the costs of different maintenance operations, while TOT_COST represents the total cost to upgrade the road.

3.3 Definition of the optimal maintenance strategies – *Utvrđivanje optimalnih strategija održavanja*

Information contained in the AHP output table (Table 6) can be used to rank the maintenance needs and thus define the priority intervention that should be funded in order to have the highest benefit. For example roads that present a higher erosion risk require more efforts to be maintained in good condition; on the other hand, according to the importance of the territory accessibility, roads with higher social value should be preferably maintained in good conditions.

Fig. 3 shows the mapping of the forest road network highlighting the parts that will be maintained with the budget of 29 000 € for regular maintenance, in accordance with different objectives. When only the social value of the roads is considered, the maintenance operations will regard a road extension of 40 km of which 31 km (77%) are actually open to traffic. Considering only the minimization of the erosion, the maintenance operations will regard 8.5 km of which 4.2 km (49%) are open to traffic. In this case, maintenance is concentrated on few roads that are evaluated as more problematic because the condition of the road is critical and maintenance interventions are more expensive.

Finally, considering the combination of the two objectives, the maintenance operations will regard an extension of 29 km of which 25.5 km (89%) are open to traffic.

Evaluating the correspondence between the priorities resulting from the AHP analysis and the actual maintenance strategies, the highest correspondence (65%) is reached with equal consideration of the two objectives, where 18.8 km of the road considered a pri-

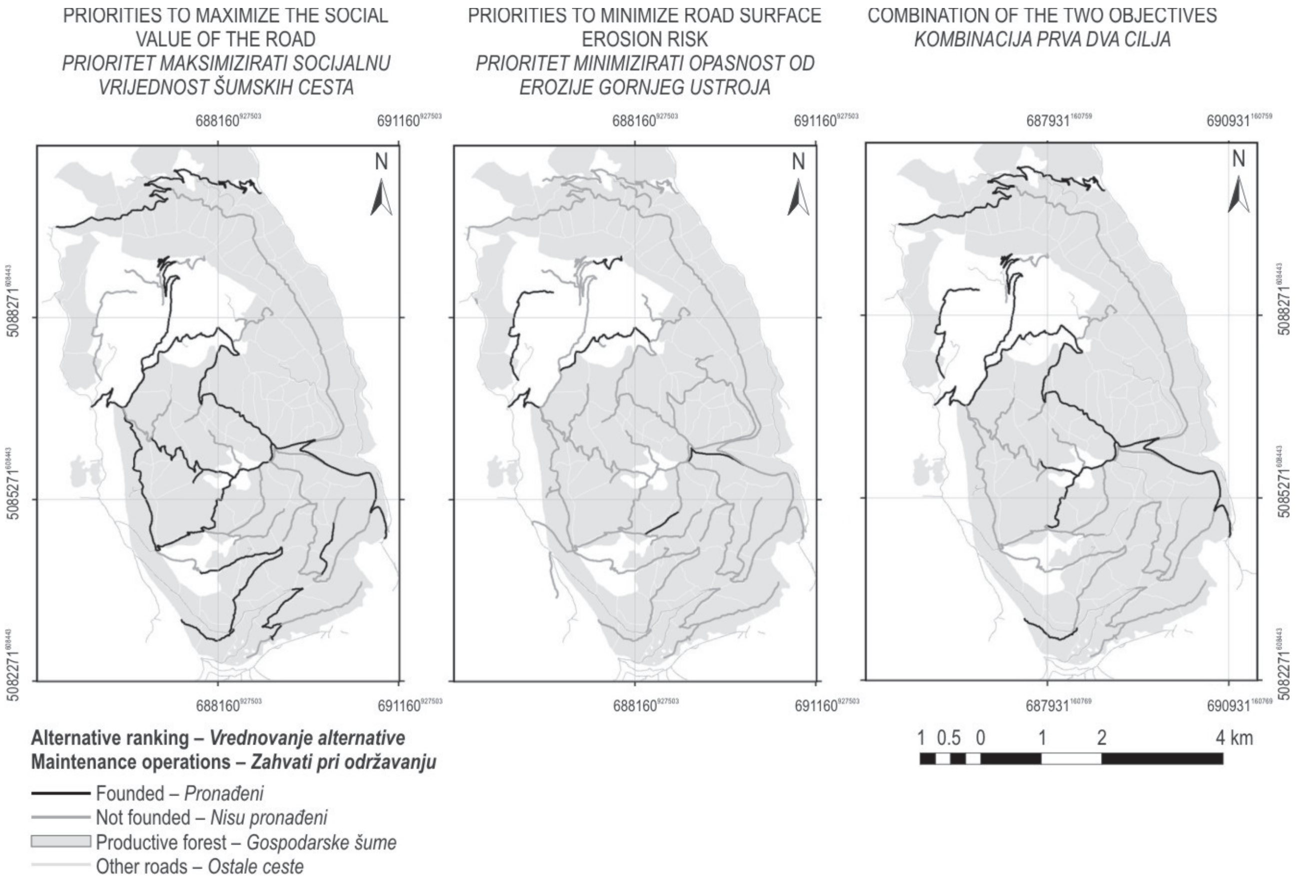

Fig. 3 Maps representing the optimal feasible maintenance strategies considering different objectives
Slika 3. *Karte predstavljaju optimalne strategije održavanja s obzirom na različite ciljeve*

ority had maintenance intervention in the last three years. In contrast, the consideration of the erosion risk has the lowest correspondence (25%) with 2.2 km that have been maintained. Finally, when the priorities defined considered only the social value, a correspondence of 56% was found, with 22.7 km that have been maintained.

4. Discussion and conclusion – *Zaključci s raspravom*

The economic resources necessary to completely upgrade the forest road network are equal to 67 000 €. Additionally, the yearly regular maintenance cost is 29 000 €. These values highlight the inadequacy of the

Table 7 Description of maintenance strategies considering different objectives
Tablica 7. *Opis strategija održavanja s obzirom na različite ciljeve*

	Total interventions *Ukupno zahvata*	Interventions on public roads *Zahvati na javnim cestama*	Correspondence with actual management *Podudaranje sa stvarnim upravljanjem*
	km	km	%
Considering social value – *S obzirom na socijalnu vrijednost*	40	31	56
Considering erosion risk – *S obzirom na rizik od erozije*	8.5	4.2	25
Considering both objectives – *S obzirom na oba cilja*	29	25.5	65

current annual budget to meet the maintenance requirements of a forest road network in the considered mountainous area. The lack of economic resources affects the »modus operandi« of the management authority that constantly has to choose which roads to keep in good condition. The current strategy guarantees constant maintenance mainly on the roads open to traffic, where road standards and level of traffic need to be higher.

Field surveys suggest that the management strategy should be reconsidered. Erosion and consequent production of sediment from the gravel road surface is a frequent process, directly connected with the worsening of the road conditions. In particular, the general lack of drainage structures seems to be one of the most important factors leading to a consistent delivery of sediment from forest road surface. Due to this situation, the opportunities for structural improvement of the management strategies have been evaluated.

In this context the integrated use of GIS tools and AHP analysis proved to be a valuable tool to better understand the ongoing processes and to give guidelines for determining the maintenance operations. The proposed methodology integrates two different aspects through the pairwise comparison process; the evaluation of the erosion risk and the evaluation of the social value of the roads considering a total of eight criteria. Additionally, the model can be adapted to the preferences of the stakeholders, who can specify which function of the forest road network should be considered preeminent for the specific vocation and needs of the analyzed area.

The resulting evaluation layer has been used to understand the benefits of the required maintenance operations and to define the priorities. The distribution of the priorities considering the combination of the two objectives justifies the maintenance strategy currently practiced, as it indicates that the available budget (29 000 €) is in large part (89%) allocated to the maintenance interventions on the public roads, and that 65% of the resources involve roads that have been recently maintained. On the other hand, the risk of erosion seems to be considered minor because only 25% of the roads with high risk of erosion have been recently maintained.

In conclusion, the use of integrated GIS tools and AHP analysis shows that different aspects can be effectively integrated. Consequently, this approach could be used to improve the efficiency of administration and management of maintenance planning, especially considering that the existing forest road system needs to evolve toward a paradigm where other benefits (e.g. recreational value) and priorities (e.g. environmental aspects) are included. Methods for the consideration of these objectives should be developed.

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Sažetak

Određivanje prioriteta pri održavanju šumskih cesta pomoću višekriterijskih modela odlučivanja: primjena u alpskom području u Italiji

U ovom radu kombinacijom GIS-a i analitičkoga hijerarhijskoga procesa (AHP) razvijen je sustav potpore pri odlučivanju (DSS) i vrednovanju prioriteta u održavanju mreže šumskih cesta.

U procesu donošenja odluka čini se da AHP ima mogućnost unaprijediti upravljanje postojećim prometnim sustavima gdje još u potpunosti nisu određeni mjerljivi odnosi između uzroka i posljedica oštećenja.

Predložena metodologija integrira procjenu rizika od erozije s vozne površine šumske ceste uz određivanje multifunkcionalnosti šumskih cesta, što se pokazalo posebno pogodnim za područja gdje se pri upravljanju šumskim cestama moraju uzeti u obzir mnoge različite funkcije koje promatrana šumska cesta obnaša.

Sustav potpore pri odlučivanju podijeljen je u četiri faze. Prva i druga faza bave se ciljevima analize i definiraju hijerarhijsku strukturu rješavanja problema. U tim su fazama definirani čimbenici (kriteriji) kako bi se naglasili ciljevi *analize te su definirane metode procjene. Skup kriterija i hijerarhijska struktura DSS-a razvijeni su istraživanjem relevantne literature i analiziranjem mišljenja stručnjaka i ostalih interesnih skupina. Kriteriji koji su korišteni pri procjeni erozijskih procesa su: uzdužni nagib ceste, stanje gornjega ustroja, stanje sustava (elemenata) odvodnje, učestalost prometa (prometno opterećenje), položaj šumske ceste s obzirom na poprečni nagib. Kriteriji korišteni pri procjeni socijalne vrijednosti šumskih cesta su: turističko značenje (pristupačnost turističkim znamenitostima), kategorija šumske ceste, poljoprivredno značenje (pristupačnost poljoprivrednim gospodarstvima/farmama) i gospodarska važnost (pristup šumskoj površini).*

U trećoj je fazi primijenjena analiza AHP-a, uz uporabu specijalne aplikacije u GIS-u, pri izračunu (ocjeni) pojedinih slojeva koji predstavljaju važnost svake ceste s obzirom na zadane ciljeve. Vrijednost pojedinih slojeva korištena je u četvrtoj fazi pri rangiranju zahvata u održavanju šumskih cesta.

Navedena metodologija testirana je na mreži primarnih šumskih prometnica u alpskom području u Italiji ukupne duljine od 107,80 km.

Na terenu su prikupljeni podaci o najvažnijim obilježjima pojedine šumske ceste. Terenska je izmjera uključivala širinu šumske ceste, tip gornjega ustroja, stanje vozne površine, prometna ograničenja, pojavnost i učinkovitost elemenata sustava odvodnje, funkcionalnu i operativnu raščlambu. Potreba za održavanjem elemenata sustava odvodnje i stanje vozne površine procjenjivana je vizualno.

Definirane su četiri vrste radnih operacija pri održavanju šumskih cesta te su projektnom analizom ustanovljeni prosječni jedinični troškovi svake radne operacije. Stvarni je proračunski limit određen kao iznos sredstava koja se najčešće utroše pri održavanju šumskih cesta.

Rezulat je analize niz karata na kojima su prikazani prioriteti održavanja za svaku istraživanu šumsku cestu. Usporedba navedenih rezultata sa stvarnim stanjem šumskih cesta na terenu pokazala je da je integrirana upotreba GIS-a i AHP-a vrijedan alat pri vrednovanju gospodarske važnosti pojedine šumske ceste i pri definiranju prioriteta u održavanju mreže primarnih šumskih prometnica radi povećanja ukupnih koristi uz minimalni utrošak novčanih sredstava.

Prikazana se metoda može primijeniti za poboljšanje učinkovitosti pri upravljanju i planiranju održavanja šumskih cesta, uzmajući u obzir činjenicu da se postojeća mreža šumskih cesta mora razvijati prema pretpostavci da su ostale koristi (npr. rekreativna vrijednost) i prioriteti (npr. ekološke značajke) uključeni.

Ključne riječi: održavanje šumskih cesta, troškovi održavanja, AHP, GIS, DSS

Authors' address – *Adresa autorâ*:

Marco Pellegrini, PhD.*
e-mail: marco.pellegrini@unipd.it
Stefano Grigolato, PhD.
e-mail: stefano.grigolato@unipd.it
Prof. Raffaele Cavalli, PhD.
e-mail: raffaele.cavalli@unipd.it
University of Padua
Department of Land, Environment, Agriculture and Forestry
Viale dell'Università 16
35020 Legnaro (PD)
ITALY
* Corresponding author – *Glavni autor*

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