Original scientific paper

Planning Forest Road Network in Natural Forest Areas: a Case Study in Northern Bosnia and Herzegovina

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Abstract

Natural forests are one of the three types of forest management in terms of origin. These forests are of seed origin and they regenerate naturally. Therefore, natural forests are the most important forest category from the point of view of timber production, as well as its quality and biodiversity. The natural forests accessibility and overall forest accessibility are insufficient for sustainable forest management. This is the reason for dealing with planning of forest roads, actually planning of forest accessibility and designing of forest roads in this forest category. This task requires quantity and quality analysis of the current forest road network, determination of optimal density of forest roads, determination of suitability of forest area for the construction of forest roads and designing of forest roads in the end. Planning of forest roads is carried out at strategic level. Analytic Hierarchy Process (AHP) allows the selection and evaluation of influential factors related to planning of forest roads. The tools of Geographic Information System (GIS) allow a complete spatial and statistical analysis and management of data collected from the forest management plans or data surveyed in the field and obtained by means of »Digital Terrain Model« (DTM) and AHP method. Planning of forest roads will be done in the Management Unit (MU) »Prosara«, located in the northern part of Bosnia and Herzegovina (BIH). The current density of forest roads is 7.3 m/ha in natural forests of this management unit. The optimal density of forest roads should be 17 m/ha. The length of new forest roads designed in the MU »Prosara« is 21 km, and forest accessibility has increased to 13.5 m/ha.

Keywords: forest road network, planning, forest road density, AHP, Bosnia and Herzegovina

1. Introduction and research problem

Sustainable forest management is based on forest accessibility whose aim is to achieve an optimal density of forest roads. Overall forest accessibility in Bosnia and Herzegovina (BIH) is 10 m/ha (Sokolović and Bajrić 2013, Bureau of Statistics of Republika Srpska (RS) 2015). It is insufficient for normal and intensive forest management in accordance with IUFRO 1995 recommendations. The second problem of forest management is that there are no studies on forest accessibility for each forest management area and forest management unit, and there are no data about optimal density of forest roads for these areas. They contain lists of compartments and length of forest roads that should be designed in the forest management plans. Therefore, it has been decided to deal with planning of forest accessibility, the actual accessibility of natural forests. Planning of forest accessibility is the first phase in planning of forest roads, while the second phase is designing of forest roads (Potočnik 2004).

Planning of forest accessibility includes determination of optimal forest accessibility, which is expressed by an optimal density of forest roads or optimal road spacing. The optimal density of forest roads should ensure more rational, more complete and more successful forest management with minimal impact on the environment (Pentek et al. 2005). Planning of forest accessibility at the strategic level requires slope classification of the terrain, by means of specific harvesting system, analyzing current forest accessibility and analyzing timber supply concerning the relief areas (Đuka et al. 2015). In accordance with the above mentioned, Krč and Beguš (2013) asked two questions: where should the new forest roads be constructed, and how many kilometers of forest roads should to be constructed. The answers to these two questions should provide enough information for planning of forest roads at the strategic level, i.e. regional level. Strategic plan of forest management should take into account production of timber, protection of the environment and social function of the forest area. One of its objectives is to determine the location and type of forest roads in the observed forest area (Fannin and Lorbach 2007).

Forest roads should be constructed in the areas suitable for the construction of forest roads. These areas are determined by evaluation of the terrain, site conditions and current forest road network i.e. current forest accessibility. Chung and Session (2001) developed forest road design method using genetic algorithm and simulated annealing method for optimization of forest road location. Multi-criteria evaluation was proposed and applied by Pičman (1994), Pentek (2002), Pentek et al. (2004), Lotfalian et al. (2008), Abdi et al. (2009), Sokolović et al. (2009), Samani et al. (2010), Enache et al. (2013), Hribernik (2013), Pellegrini et al. (2013), Hayati et al. (2013), Lepoglavec (2014), Tampekis et al. (2015), Jež (2016).

We have decided to observe natural forests because they account for 43% of the total public forest area. Public forests account for 78%, and private for 22% of the total forest area, which is 2.6 million ha or 46% of the total area. It is the most important forest category from the point of view of timber production and its quality and biodiversity. Natural forests produce 2.6 million m^3 of timber from the total amount of 2.9 million m^3 per year. Accessibility of natural forests is 11 m/ha (Sokolović and Bajrić 2013, Bureau of Statistics RS, 2015). Natural forests (high forests) are the type of forest management in terms of origin. They regenerate naturally from seeds (Bunuševac 1951, Govedar 2011); further to the above, it can be concluded that natural forests represent a bank of seeds of domestic forest trees species.

The research objectives of this paper are related to planning of forest road network in natural forests, as follows:

⇒ quantity and quality analysis of current primary forest accessibility, where density of forest roads and skidding distance will be analyzed

⇒ it has been assumed that current density of forest roads in natural forests is less than optimal density of forest roads, and insufficient for normal and intensive forest management. The average current real skidding distance and its costs are higher than the targeted average real skidding distance and its costs, and the optimal forest roads density could be achieved only over several decades

⇒ designing of forest roads – optimal length of forest roads should be distributed in the management unit area, which is insufficiently accessible and suitable for the construction of forest roads. Forest roads should be designed in accordance with applicable laws and regulations.

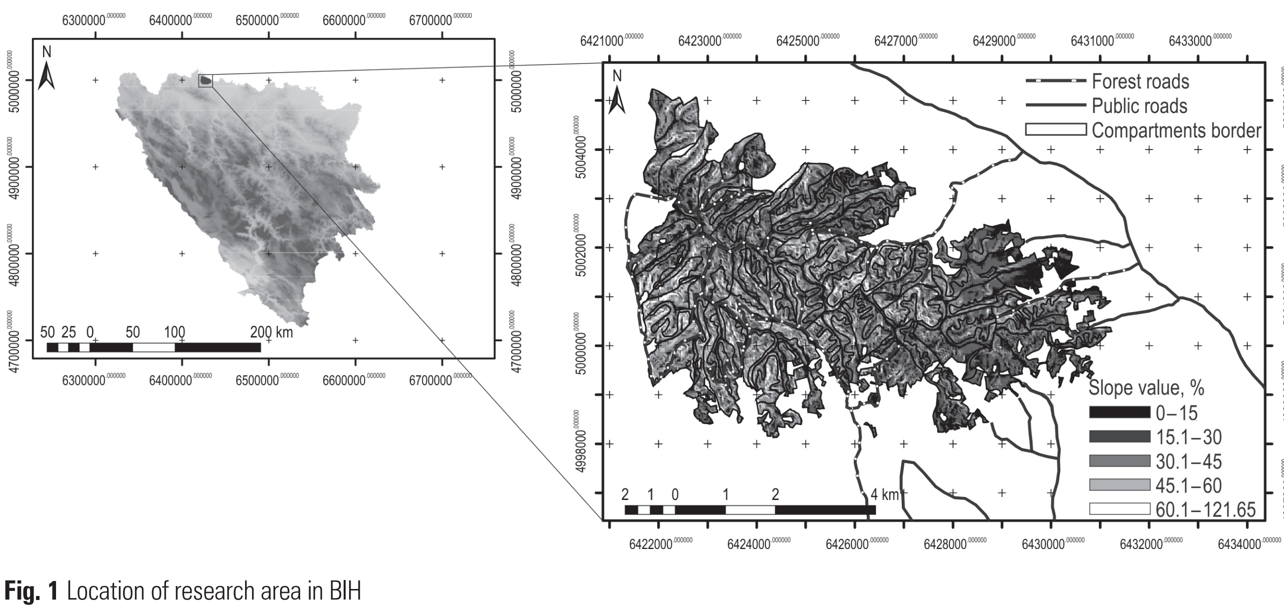

Fig. 1 Location of research area in BIH

2. Materials and Methods

2.1 Research area

The research was done in the natural forests of the Management Unit (the MU) »Prosara«, located in the mountain Prosara, in the northern part of BIH between 17°00′00″ E to 17°07′30″ E, and 45°13′00″ N to 45°17′00″ N (Fig. 1). It is managed by the Forest Administration »Gradiška«, Forest Office »Gornji Podgradci«. The forests and forest lands cover 3980 ha, and natural forests cover 3470 ha or 87% of the overall forest area in the MU. Forest vegetation grows on silicate soil, which is deep and consists of mixed forests of sessile oak with hornbeam *(Querco-Carpinetum illyiricum),* and above them, there are pure beech forests (*Fagetum illyricum*). Those are typical forests of the hilly area of the northern and central parts of the country (Stupar and Čarni 2017). The total length of forest roads in the MU is 27.83 km, and in the natural forests this length is 25.25 km. Accessibility to the overall and natural forests is equal in this MU, and it amounts to 7.3 m/ha (Public Forestry Company (PFC) »Šume RS« 2012).

2.2 Analysis of current primary forest accessibility

The first task in the research is to collect the necessary data. Data are collected from the forest management documentation such as the Forest Management Plan or operational projects. These data are the following: list of compartments and their area, management classes, growing stock, growing increment, cut volume, etc. Forest road network is recorded by GARMIN GPSMap 62st. These data are necessary for spatial and statistical analysis with ArcGIS 10 software. The results of these analyses are the current length of forest roads, current forest accessibility, and skidding distance. Determination of the current forest accessibility is based on the influence of forest roads according to the rules established by Pičman (2007). An average geometrical skidding distance is determined by means of the method measuring distance from the center of gravity of the compartments to the nearest forest road. Real average skidding distance is obtained by multiplying the geometrical skidding distance and skidding factor (Eq. 1). Skidding factor depends on the relief area, slope and presence of obstacles on the surface.

$$S_{\mathrm{dS}} = S_{\mathrm{dG}} \times k_{\mathrm{G}} \tag{1}$$

Where:

S_{dS} real average current skidding distance, m

S_{dG} geometrical average current skidding distance, m

k_{G} skidding factor (Pentek et al. 2005).

2.3 Determining optimal density of forest roads

After the analysis of the current forest accessibility, planning of forest accessibility i.e. determination of optimal density of forest roads in natural forests of the MU has been carried out. Optimal density of forest roads is calculated by FAO (1998) formula (Eq. 2).

$$c = \sqrt{\frac{100,000 \times hV}{4R}} \tag{2}$$

Where:

c optimal density of forest roads, m/ha

100,000 constant

R costs of construction and maintenance of forest roads in the period of depreciation, €/km

h costs of timber skidding for 100 m of skidder LKT 81 productivity, €/m^3

V discounted allowable cut volume of timber in lifespan of forest road, m^3/ha.

Skidding costs consist of skid trails construction costs and unit skidding costs. The skid trails construction costs depend on the costs of excavation, which are prescribed in the Description and Unit Costs of Forest Road Construction Works (2009) for certain type of soil and volume of excavation. They are divided with discounted allowable cut volume of roundwood in lifespan of forest road. Discounted volume of roundwood is calculated on the basis of an average allowable cut volume of roundwood in the natural forests, which is reduced due to delay in forest road lifespan, which is 50 years (Naghdi and Limaei 2009, Hribernik 2013) and capital interest of 4.7% (Republika Srpska Investment-Development Bank (IRBRS), 2017). The unit skidding costs are calculated as the ratio of costs of a skidder and its productivity on 100 m of skidding distance.

The total roading costs consist of the costs of forest road construction and the costs of their maintenance. The costs of forest road construction are calculated according to prices of work prescribed in the Description and Unit Costs of Forest Road Construction Works (2009) and the amount of work. They consist of the costs of excavation and filling, pavement construction and finishing, construction of drainage and planning of forest road project (Naghdi and Limaei 2009). The amount of excavation is determined on the basis of the carriageway depth and terrain inclination (0–75%). The carriageway depth is the depth where all truck wheels are on hard surface (Potočnik 2005). After that, the annual maintenance costs are calculated as the sum of costs of profiling of forest road pavement by the grader and cleaning of drainage, as well as the costs of repairing the pavement in 5 to 10 years. Total maintenance costs per km are determined on the basis of annual maintenance costs, which depend on capital interest of 4.7%, and period of forest road depreciation (50 years). The total roading costs are the sum of construction costs and maintenance costs of forest road per km. The annual construction costs of forest roads are calculated on the basis of depreciation and capital interest of forest roads. The annual roading costs are the sum of annual construction and maintenance costs.

On the basis of optimal density of forest roads, the targeted real average skidding distance is calculated by formula of Rebula (1980) (Eq. 3).

$$Sd_{\mathrm{os}} = \frac{k_{\mathrm{S}}}{c} \times 10{,}000 \qquad (3)$$

Where:

Sd_{OS} targeted real average skidding distance, m

k_{S} theoretical total skidding factor

c optimal density of forest roads, m/ha.

Optimal forest accessibility is observed from the point of view of relative forest accessibility and efficiency coefficient of the forest road network, except optimal density of forest roads. Relative forest accessibility (O_{R}) is the ratio of the accessible forest area and the total forest area (Eq. 4).

$$O_{\mathrm{R}} = \frac{P_{\mathrm{O}}}{P_{\mathrm{U}}} \times 100, \% \qquad (4)$$

Where:

P_{O} accessible forest area, ha

P_{U} total forest area ha.

The accessible forest area is obtained by creating a buffer zone around the forest roads, whose width is equal to the targeted double geometrical average skidding distance. The areas outside the buffer zone are insufficiently accessible (Pentek et al. 2005).

The efficiency coefficient of the forest road network (k_{U}) is the ratio of a forest area accessible by a single forest road and multiple forest roads (Eq. 5).

$$k_{\mathrm{U}} = \left(1 - \frac{P_{\mathrm{N}}}{P_{\mathrm{O}}}\right) \times 100, \% \qquad (5)$$

Where:

P_{N} surface of inefficiency of bordered areas (multiple accessible area), ha

P_{O} accessible area for the chosen targeted double geometrical skidding distance (single accessible area), ha (Pentek et al. 2005).

When the planning phase of forest accessibility is completed, the phase of designing of forest roads starts. This economic length of forest roads per ha should be laid in the area of natural forests, which are insufficiently accessible and suitable for construction of forest roads.

2.4 Designing of forest roads

Multi-criteria analysis of relief and site factors will determine the areas suitable for construction of forest roads. The selected factors are the following: slope of terrain, depth of soil, normal and current growing stock. Terrain slope is one of the most important factors during designing of the forest road in terms of suitability of the forest road and terrain after construction. The raster of terrain slope will be obtained from DTM with resolution 5×5 m. Soil depth is easy measurable in the field and, in combination with the cross slope, it can have great influence on forest road construction. Shallow soils on mildly sloped terrains and deep soils even on steeper terrains demand less construction costs, that is, soil works (Sokolović et al. 2009). Normal and current growing stock are indicators of potential and current site production. The rasters of soil depth, normal and current growing stock are obtained from the attribute table with Arctool Feature to raster. Original values of these factors are standardized by Eq. 6 to values 0 to 1.

$$X_{\mathrm{i}} = \frac{(R_{\mathrm{i}} - R_{\mathrm{min}})}{(R_{\mathrm{max}} - R_{\mathrm{min}})} \times X_{\mathrm{max}} \qquad (6)$$

Where:

x_{i} standardized value

R_{i} basic value

R_{min} lower value of basic scale

R_{max} upper value of basic scale

X_{max} upper value of standardized scale.

The standardized rasters are entered into Arctool Weighted Sum and multiplied by the weights of influential factors, which are summed. The results of this analysis are two maps of suitability. The first map is the map of optimal suitability obtained by summing the terrain slope, depth of soil and the normal growing stock rasters. The second map is the map of the actual suitability of the natural forest area for the construction of forest roads and it is the result of summing the terrain slope, depth of soil and the current growing stock rasters. These rasters are divided into three classes: 0–0.33 unsuitable area, 0.33–0.66 medium suitable area and 0.66–1 highly suitable area.

The weights of influential factors are obtained by AHP method based on the opinion and experience of fourteen forest engineering scientists. This method has been developed by Tomas Saaty as a tool of decision-making analysis. It is created as an auxiliary tool of

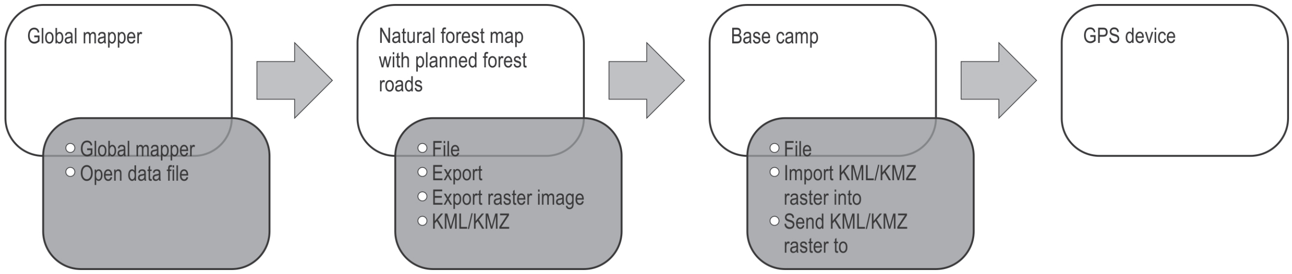

Fig. 2 Process of sending of planned forest roads into GPS device

engineers in multi-criteria decision-making. Decision-making group consists of engineers or scientists, who evaluate the importance of the criteria for a given problem. Their average grades are standardized by Eq. 6, and after that, a pair-wise comparison matrix is created, based on which weights of the criteria are calculated. Evaluation of importance of the criteria for the problem is a result of experience and opinion of decision-makers, and it is necessary to calculate consistency ratio CR in order to determine the accuracy of the evaluation. CR is the ratio of consistency index CI and RI random index. The AHP can be implemented in three simple consecutive steps: evaluation of importance of the criteria, computing the vector of criteria weights and consistency calculation (Saaty1980, Saaty 2008, Pellegrini 2013, Hribernik 2013, Lepoglavec 2014, Jež 2016).

During designing of forest roads, protection of soil and protection of quality and stability of forest roads should be taken into account. Forest roads will be designed in the area whose slope is up to 60% (Keller and Sherar 2003), and the maximum longitudinal slope of forest roads is up to 8% from the poibt of view of risk of erosion and type of soil (PFC »Šume RS« 2002b, Potočnik 2004). It is the most important constructive element of forest roads in terms of maintenance of forest roads. Designing of forest roads is carried out by plotting of a zero line on contour map. Plotting of a zero line is carried out by using ArcGIS Toolbar Editor, Edge Snapping tool Length. The raster of natural forest area with the plotted zero lines was imported in software GlobalMapper and it was saved in kmz or kml format. The raster was imported into BaseCamp software and later it was sent to GPS device (Fig. 2) to be set up in the field.

3. Results and Discussion

3.1 Analysis of current primary forest accessibility

The total length of the forest roads surveyed is 34.93 km, but 31.02 km or 88% were taken into account for calculating the overall forest accessibility by Pičman's method (2007), where the location of the forest road regarding the forest area is taken into consideration. According to these data, the density of forest roads is 7.8 m/ha in Prosara, and 9.04 m/ha in its natural forests. The natural forests accessibility is 10 m/ha in BIH (Sokolović and Bajrić 2013, Bureau of Statistics of RS 2015). The densities of forest roads in the natural forests of the MU and in the natural forests of BIH do not allow for intensive forest management (IUFRO 1995). The overall forest accessibility in BIH is 2 to 6 times lower than forest accessibility in other countries in the region. For example, the forest accessibility is 7 to 30 m/ha in Croatia (Pentek et al. 2007), and around 25 m/ha in Slovenia (Krč and Beguš 2013). An average density of forest roads is 45 m/ha in Austria (Ghaffarian et al. 2009).

Forest accessibility depends on the relief of the region where the forest area is located. According to that, FAO (1998) recommended the density of 7 to 10 m/ha of forest roads in hilly relief region. Minimum required current density of forest roads is 7 m/ha in lowland region and 12 m/ha in hilly region of Croatia. Current density of forest roads is 8.85 m/ha in lowland- relief region and 11.26 m/ha in hilly relief region. Planned density of forest roads should be 15 m/ha in low-land region and 25 m/ha in hilly region up to 2020 (Pentek et al. 2011). According to Bertović (1999), the elevation raster was obtained by spatial analysis of DTM and it is classified into two relief regions, lowland and hilly relief regions. The first region accounts for 30%, and the second for 60% of the MU. According to that, current density of forest roads is sufficient. However, current density of forest roads in the natural forests of the MU »Prosara« should be increased when taking into account the quality of forest management and especially the results and recommendations of the above mentioned research.

Current average geometrical skidding distance is 510 m. It was determined by the method of distance from the center of gravity of compartments to the nearest forest roads (Fig. 3). Skidding factor for this

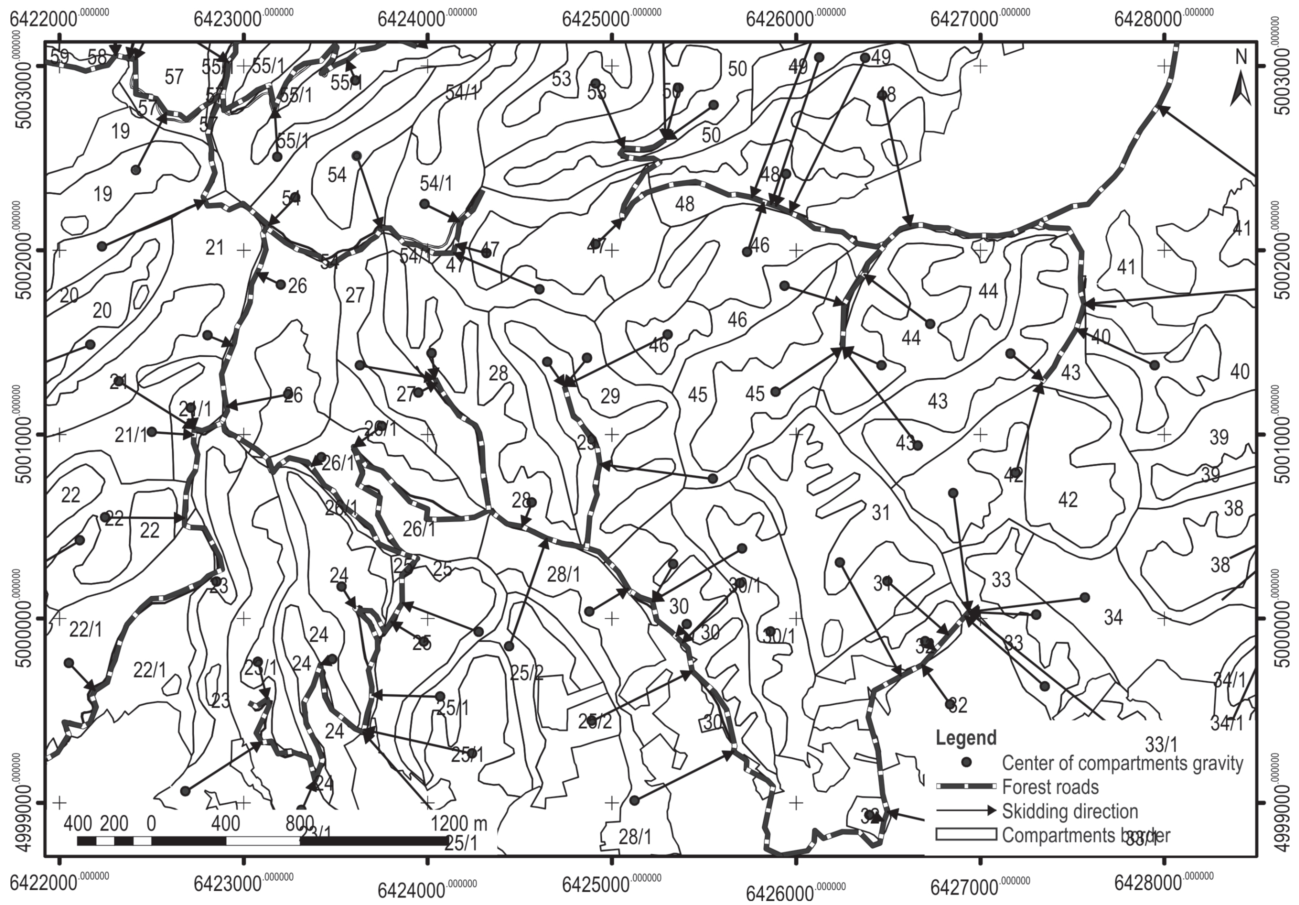

Fig. 3 Determination of average skidding distance

management unit is 1.5 (Petković et al. 2015) and real average skidding distance is 765 m. Skidding costs, according to the cost of the skidder LKT 81 per work day and its productivity for the real average skidding distance, are 10.62 €/m^3.

3.2 Determining of the optimal density of forest roads

Forest accessibility will be expressed by density of forest roads, which depends on transportation costs and allowable cut volume of roundwood. Transportation costs consist of skidding and roading costs and their calculation was stated above.

The skidding costs consist of construction costs and unit costs of skidding. Construction costs of skid trails were obtained by multiplying the costs of excavation and the amount of excavation. The unit costs of excavation are 2.44 €/m^3 (PFC »Šume RS« 2009), considering the type of soil that belongs to the terrain category 3 (Jeličić 1983). The volume of excavation on terrain category 3 is 0.5 m^3/m (Jeličić 1979). An average allowable cut volume of roundwood is 39.54 m^3/ha in the natural forests and according to that, discounted roundwood volume is 92.1 m^3/ha. Costs of construction of skid trails are 0.01 €/m^3. The unit skidding costs, taking into consideration the cost of the skidder LKT 81 of 324.52 €/WD[1], as regulated by the Decision of PFC »Šume RS« No. 01-2166/12 from 2012, its productivity for the skidding distance of 100 m, the average tree volume of 0.5 m^3 and winching distance of 30 m, are 58.58 m^3/WD (PFC »Šume RS« 2002a) or 5.54 €/m^3. The total skidding costs are 5.55 €/m^3. The skidding costs are 8.93 \$/m^3 or 8.24 €/m^3 for Timberjack skidder and 8 \$/m^3 or 7.38 €/m^3 for Clark skidder for the skidding distance of 500 m or 9 m/ha of forest road density (Naghdi and Limaei 2009). According to the same skidding distance and unit costs of skidding, the costs of skidding of LKT 81 is 8.82 €/m^3. When comparing the skidding costs, it can be seen that the Clark skidder is more suitable for skidding than the other two skidders.

[1] WD-work day-8 hours work shift

The calculation of the total roading costs was described above, and according to the unit costs of the construction of forest roads, and prices of work, which are prescribed in the Description and Unit Costs of Forest Road Construction Works (2009), and the amount of work, these costs are 31,737 €/km. Enache et al. (2011) have calculated that the overall average road construction costs are 33.52 €/m or 33,520 €/km. The annual maintenance costs are 720 €/km, and total maintenance costs are 13,248 €/km, depending on the lifespan of forest road and capital interest. According to that, the total roading costs are 44,985 €/km. The annual construction costs of forest road are 1725 €/km, and hence, the total annual roading costs are 2445 €/km. The annual roading costs were 3647 $/km or 3428 €/km in 2009 (Naghdi and Limaei 2009). Building of forest road retaining walls was not planned, and if the possible differences in the cost of fuel and labor were added here, the difference between the roading or road construction costs could be justified.

Optimal density of forest roads in natural forests, calculated based on transportation costs and cut volume of timber by FAO (1998) formula, is 17 m/ha. According to the given density, the targeted real average skidding distance should be 353 m, which is shorter by 412 m than the current skidding distance. The skidding costs for the real average skidding distance are 8.44 €/m^3, or 2.18 €/m^3 lower than the current skidding costs. The average targeted geometrical skidding distance will be 235 m if the skidding factor is 1.5.

This optimal density allows normal forest management in accordance with IUFRO 1995. The average optimal density is higher than the current density of forest roads by 10 m/ha. Achieving optimum density of forest roads leads to the reduction of skidding distance and skidding costs, and it is the aim of planning of forest accessibility (Jež 2016).

The accessible natural forest area is 1974.36 ha for the targeted double average geometrical skidding distance (235 m). The relative natural forest accessibility is 57%, and it means that natural forests of this MU are poorly accessible according to Pentek et al. (2005) (Fig. 4).

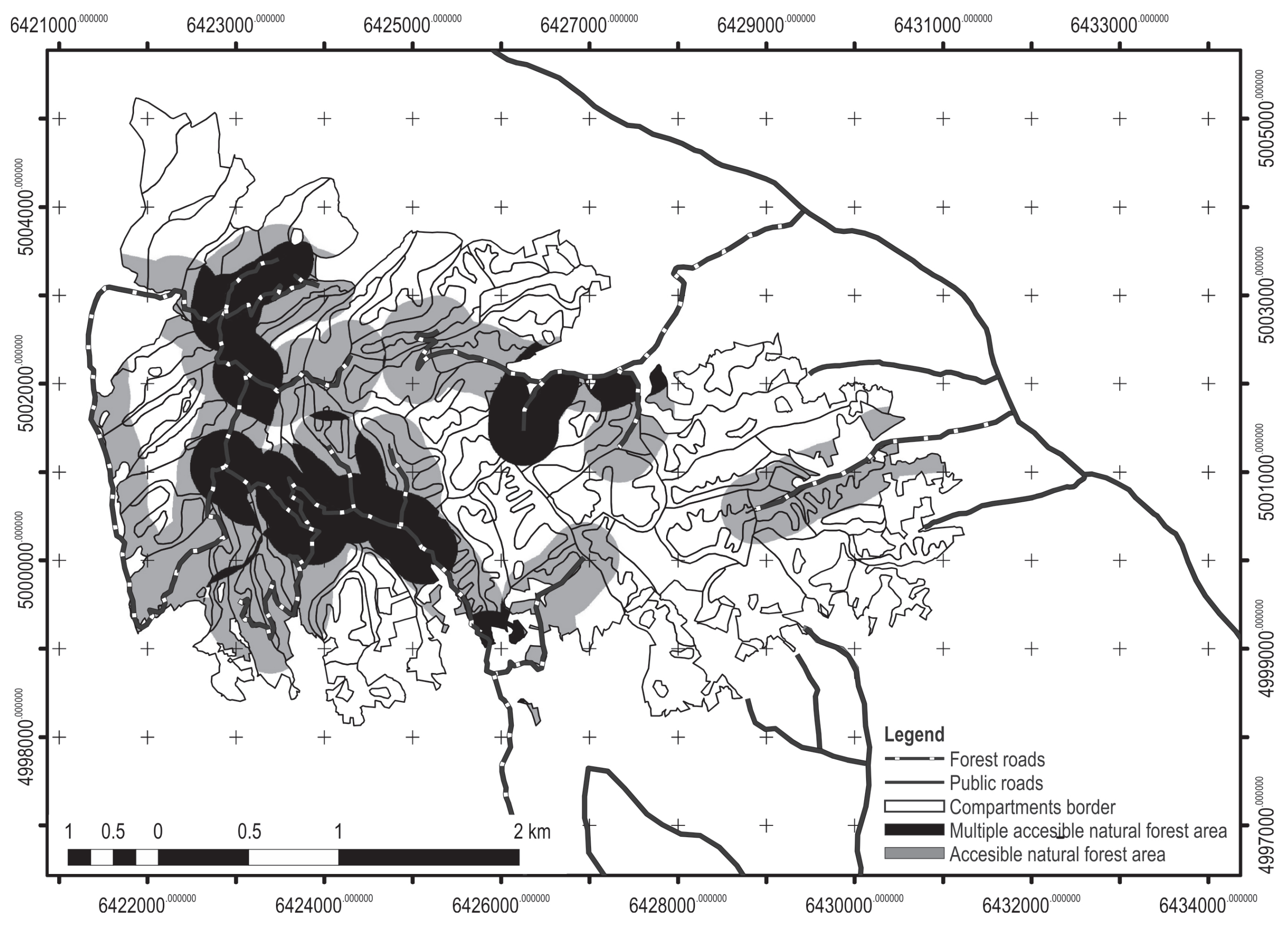

Fig. 4 Efficiency coefficient of forest road network

Multiple accessible natural forest area is P_N = 931.26 ha, single accessible natural forest area is P_O = 1974.36 ha, and the efficiency coefficient of the forest road network is 53% (Fig. 4).

However, whether this optimal density of forest roads would be achieved, depends on the terrain and site conditions of a certain area, i.e. the MU. In order to achieve the optimal density of forest roads, it is necessary to design forest roads in the MU.

3.3 Designing of forest roads

The forest roads are designed as zero lines on the map of optimal suitability of natural forest areas, which are medium and highly suitable for the construction of forest roads and insufficiently accessible (Fig. 5).

The results of AHP analysis are weights for the terrain slope (0.42), for soil depth (0.19) and for growing stock (0.40). The weights were obtained by AHP method in other studies, and they are: 0.2–0.4 for slope, 0.15–0.2 for soil and 0.02–0.1 for timber volume (Abdi et al. 2009, Samani et al. 2010). Lepoglavec (2014) uses the same weights (0.25) for each influential factor, i.e. the ratio between 1 and the number of influential factors. When comparing the weights of influential factor for determining suitability of natural forests area, which were obtained in this study and in other studies, it can be seen that weights of terrain slope and soil are similar, while the weight of timber volume is bigger in our study than in some other studies. The results of spatial analysis show that 24 ha or 1% of the total area of natural forests are unsuitable for construction of forest roads, 2147 ha or 63% of the total area are medium suitable and 1246 ha or 36% of the total area are highly suitable for construction of forest roads (Fig. 4). The aim of designing forest roads is the reduction of skidding distance and skidding costs with the increase of density of forest roads, i.e. the forest accessibility.

Enache et al. (2013) developed a decision support tool for evaluating different forest road options before designing a suitable variant based on stakeholder's preference and multicriteria analysis. The main process refers to locating a new road, productivity assessment, calculation of extraction costs and evaluation of impact on the environment and the utility analysis of forest road alternatives. The multiple attribute utility theory (MAUT) was proven as an appropriate tool for evaluating forest road alternatives for its simplicity and its practicality in the development of decision support tools in the sector of forest engineering.

In practice, GIS tools and AHP analysis are valuable tools for determining maintenance activities. This approach uses pair-wise comparison process, the evaluation of erosion risk and the evaluation of social value of roads based on stakeholders preferences, so as to determine the function of forest road in the analyzed area (Pellegrini et al. 2013).

Important criteria for forest road planning were selected in 3 rounds by Delphi method. After that, the selected criteria were used for developing the pairwise comparison questionnaire, which was sent to the participants in order to obtain the weight of each criterion. Their answers were analyzed by the Expert Choice software, and finally the weights of all the criteria were obtained (Hayati et al. 2013).

Multi-criteria analysis was also used in the paper of Tampekis et al. (2015), who evaluated the type of criteria, such as intensity and absorption, in order to determine spatial distribution of optimal forest roads density in the forest area. The intensity criteria evaluation means the environmental impacts, which are caused by forest roads in the forest area. The evaluation of absorption criteria refers to the ability of the environment to absorb the impacts caused by forest road construction. This method refers to non-productive forests. Criteria evaluation and selection of alternatives from the point of view of productive, protective and social function of forests are a thread that connects the papers.

Keeping in mind soil protection from erosion and the costs of forest road construction, the forest road will be designed in the area with the slope up to 60%. Terrain slope raster is obtained by spatial analysis of DTM, and the slope ranges between 0 and 121% in the natural forests of the MU, while the average slope is 27% or 15°. Statistical analysis showed that the slope of 3342 ha or 97.4% of the total natural forest area of the MU was up to 60%, and the slope of 86.6 ha or 2.6% of the total natural forests area of the MU was over 60%. Therefore, roundwood will have to be extracted by skidder LKT 81.

The maximum slope gradient acceptable for skid trails construction varies between 45% and 60% in BIH. The roundwood was produced by motor-manual assortment method, which is the most common harvesting method in BIH. However, skidder works under its capacity in the assortment method (Marčeta 2014).

21 km of zero lines have been plotted (Fig. 5) for new forest roads, and the total length of forest roads, which make the natural forests of the MU »Prosara« accessible, is 46.25 km, while the new density of forest roads is 13.5 m/ha. This new density of forest roads does not allow normal forest management, almost in

the same way as the current density of forest roads. It is lower than the calculated economical optimum density of forest roads, and the reason for this is probably the relief. Some of the planned zero lines are connected to public roads, which shows that modern forest management should also take into account the quality of life of inhabitants in the forest area, and this represents a social moment of forest management.

The average geometrical skidding distance is 271.5 m, and the real average skidding distance is 407 m. It is 358 m shorter than the real current skidding distance. The skidding costs should be 8.77 €/m^3 on the basis of this skidding distance, and it is 1.85 €/m^3 lower than the current skidding costs.

The construction of 21 km of these new roads should cost 666,480 €, and this was calculated on the basis of the estimated costs of forest road construction, which are 31,737 €/km.

The total saving of skidding costs could amount to 253,321 € in 10 years, or 25,332 € per year and this has been calculated on the basis of the saving of skidding costs as a result of the shortening of skidding distance, which is 1.85 €/m^3 and total cut volume of roundwood of 137,216 m^3. The total savings of skidding costs could justify 38% of construction costs of 21 km of new forest roads.

By these savings of skidding costs, 8 km could be constructed in 10 years, which means that 21 km of forest roads could be constructed in 26 years.

4. Conclusions

The results of earlier researches show that GIS, GPS, RoadEng are very useful tools in planning forest accessibility and forest management. Forest accessibility depends on many factors, such as: terrain conditions, site potentials, transportation costs, demands and supply of timber, social demands, etc.

Planning of forest roads consists of the planning of forest accessibility and designing of forest roads. Planning of forest accessibility requires determination of optimal density of forest roads or optimal spacing of

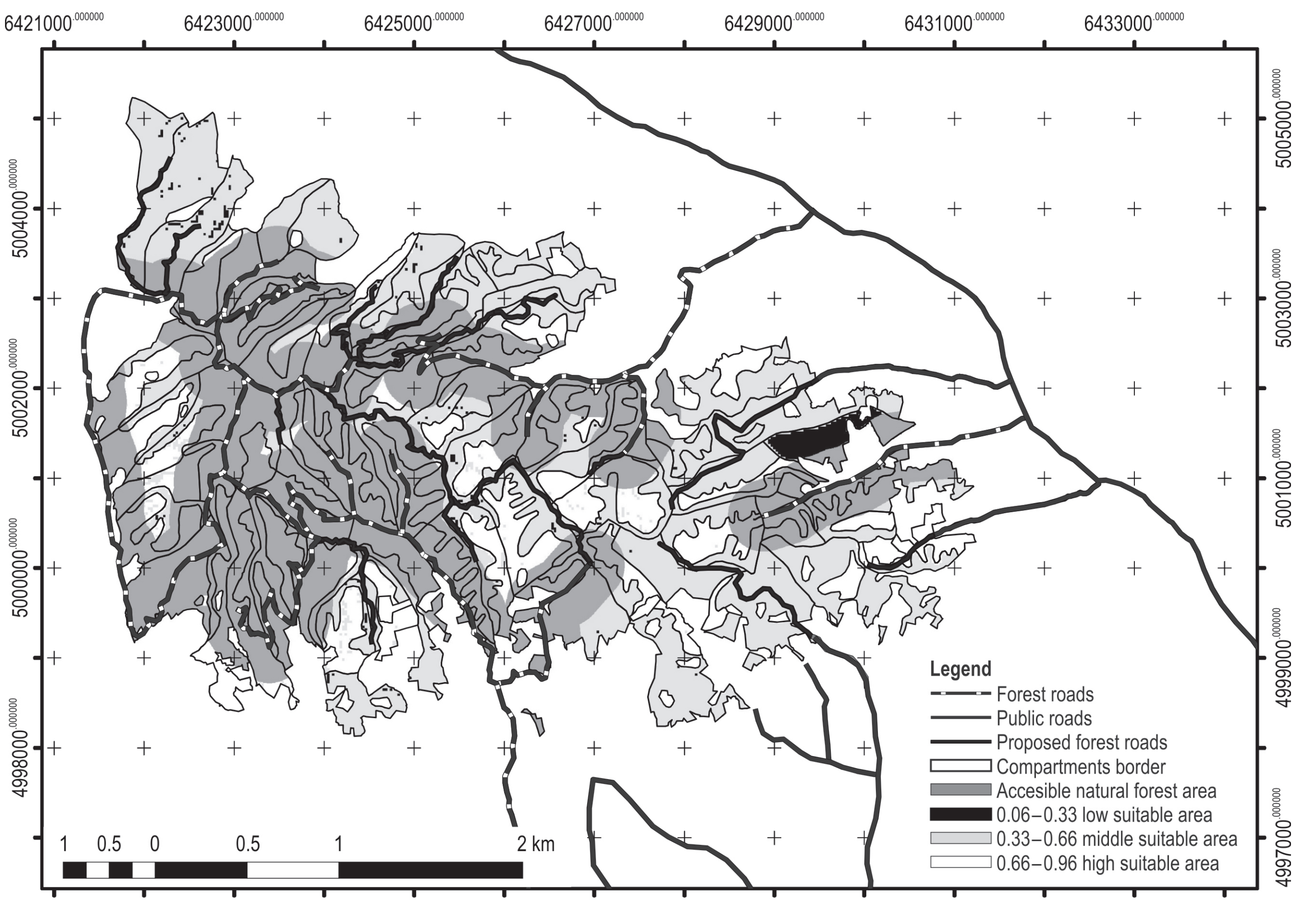

Fig. 5 Proposed forest roads in suitable and insufficiently accessible areas of natural forests

forest roads. Forest accessibility was considered from the point of view of timber production and transportation costs.

The second phase of the planning of forest roads is their designing in the field. The forest roads were represented by zero lines at the strategic level of forest road planning. The zero lines have been laid on the contour map into the areas which are suitable for construction of forest roads with horizontal and vertical alignments according to the Manual for Design of Forest Truck Roads (2002b), and considering protection and social function of the forest environment. Determination of suitability of the forest area for the construction of forest roads should be considered from the point of view of terrain conditions and growing stock of timber.

The assumptions stated below have been confirmed by the analysis of accessibility of the current forest road network and calculation of optimal density of forest roads:

⇒ the current density of forest roads is lower than optimal

⇒ the real average current skidding distance is bigger than the real average targeted skidding distance, meaning that the costs of skidding for the real average targeted skidding distance are lower than the costs of skidding for real average current skidding distance

⇒ density of the current and proposed forest roads designed on the contour map can be achieved in 26 years on the basis of skidding cost savings, which can justify 38% of the necessary construction costs of forest roads.

Based on the results, it can be concluded that:

⇒ it is necessary to establish a cadastre of forest roads with respective database

⇒ forest accessibility should be expressed by density of forest roads, skidding distance, relative forest accessibility and the efficiency coefficient of the forest road network

⇒ the approach of planning forest accessibility at strategic level has been obtained by determining the suitability of the forest area for the construction of forest roads with ArcGIS 10 software. The selected factors affecting the determination of an area suitability for the construction were evaluated by AHP method

⇒ forest roads have been designed as zero lines plotted on the contour map and laid on the field. This approach enables spatial distribution of the economic length of forest roads for the natural forests into areas which are suitable for construction of forest roads and in accordance with applicable standards

⇒ the findings of the research should renew the practice of making the Study of Forest Accessibility for management units.

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