Taylor & Francis
Taylor & Francis Group

JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648–6897 print/ISSN 1822-4199 online
2012 Volume 20(1): 58–66
doi:10.3846/16486897.2012.662748

DESIGNING AN OPTIMAL FOREST ROAD NETWORK BY CONSIDERATION OF ENVIRONMENTAL IMPACTS IN GIS

Seyed Ataollah Hosseini[1], Mohammad Reza Mazrae[2], Majid Lotfalian[3], Aidin Parsakhoo[4]

Department of Forestry, Faculty of Natural Resources,
Sari Agricultural Sciences and Natural Resources University,
Mazandaran Province, Sari city, P.O.Box 737, Iran
E-mails: [1]Ata_hosseiny2002@yahoo.com; [2]M.Mazrae@gmail.com;
[3]Mlotfalian@yahoo.com; [4]Persian3064aidin@yahoo.com (corresponding author)

Submitted 04 Jun. 2011; accepted 04 Jul. 2011

Abstract. Planning of forest road network is the most important issue for sustainable management of northern forests in Iran. This study represented a technical method of forest road planning by using GIS (Geographic Information Systems) in Vatan forestry plan of Golestan province, Iran. The aim of this study was to find out options for the optimization of skid trail length and for decreasing the negative effects of redundant skid trail length. Results of this study showed that the total length of forest road and the road network density was 36745 m and 8.68 m ha^{-1}, respectively. 54% of the area was covered by these roads. 98.06 km skid trail was planned from road verge into the forest interior. The density of this skidding trail was 23.17 m ha^{-1}. The suggested road network length measured using GIS was 47.23 km. Road density was 10.87 m ha^{-1}, with 79% coverage. Skid trail length was 81.04 km, and skid trail density was 19.15 m ha^{-1}. On the basis of GIS measurements, the skid trails on new road network system had shorter length and more frequency. This causes to decrease the cost of primary transportation. Moreover, in this plan the roads with suitable coverage passed from stable slopes.

Keywords: road network, skid trail, optimization technique, geographic information system, Vatan forest, Iran.

1. Introduction

Optimal road density is an important factor to help forest engineers to optimize the harvesting costs using a suitable road network (Ghaffarian, Sobhani 2008). To find optimal locations for the road network, many forest engineers still use traditional methods that are almost entirely manual. Several attempts have been made already on the use of geographic information system (GIS) for forest road network optimization in Iran and elsewhere (Freycon 1999). Scientists combine main factors in the selection of the most suitable forest roads including hillside slope, hillside aspect or direction, soil, volume of trees per hectare as well as ecological capability of using GIS (Hosseini *et al*. 2004; Akay, Sessions 2005; Akay 2006). Planning road on a topographic map and then routing on the field are the main phases of forest road network construction project. This operation need to be done by forestry experts (Sobhani, Naiaj Nouri 2006).

Building and maintaining roads may have environmental and social problems for sustainable forestry in short- and long-term (Cole, Landres 1996; Williams 1998). The accelerated development in computer software and hardware particularly during the last few decades has made topical the use of such systems as a significant tool in the realization of space analysis, planning, management and decision making (Demir, Ozturk 2004). Many researchers attempted to develop a new method for improvement of forest road network planning (Dean 1997; Ariel, Lugo 2000; Anderson, Nelson 2004; Demir, Ozturk 2004; Aruga 2005; Ghaffarian, Sobhani 2007; Najafi *et al*. 2008).

Heralt (2002) mentioned in his study in Romania that road network designing depends on not only costs, but also other factors such as local distribution of existing forest roads, landscape pattern, and hydrology and soil properties must be taken into account when developing a road network. Pentek *et al*. (2005) performed a quantitative analysis of an existing road network in Croatia applying GIS. Several factors such as length condensation, distance condensation and network percentage were calculated. Rafatnia *et al*. (2006) showed that using GIS could prepare the feasible road network for interested area and important land uses such as forest and tourism areas. So, projection, rapid evaluating of routes and considering of different multiple factors in routing have been possible using GIS capability and information management. Babapour *et al*. (2006) applied GIS and PEEGER software for producing stability map and planning a new road network.

By evaluating alternative routes in the office using available GIS routines, days or even weeks of valuable field time can be saved and ultimately, a better design may emerge. GIS technology has opened up new horizons in transportation planning and especially in travel demand modeling. It provides the tool that a transport planner would need to convey ideas and present implications of planning decision visually for non-planners (Abdi *et al*. 2009).

By technically increasing the road length, the distance between roads and cost of wood transportation will decrease (Naghdi *et al*. 2008). Moreover, increasing road length causes an increase in the road construction and maintenance cost. So the cost in wood transportation and road construction should be balanced by a technical forest road network that accesses the forest areas with minimized road length (Eghtesadi *et al*. 2002; Murat, Tolga 2004).

With use of the digital elevation model (DEM) and the assessment of slope steepness and soil conditions in an area, the road network is planned appropriately in technically, economically and ecologically point of view. Accordingly, optimum transportation plans will be established in line with this optimal road planning (Demir, Ozturk 2004; Hosseini *et al*. 2004).

In general, GIS is a technique that is used to estimate quantitative variables from remotely-sensed data. Therefore, the objective of this study is to find out options of optimization of forest road spacing and skid trail length for decreasing the negative effects of redundant length of routes. Moreover, the optimal forest road network is compared with existing network using GIS.

2. Methods

Study area

Vatan forest is located at Golestan province, 25 km in Azadshahr in watershed number 40 (36° 55‘ to 37° 00‘ N and 55° 12‘ to 55° 17‘ E). The study area is 4231 hectares (ha) with 57 parcels. The bedrock of study area has a thick layer of lime. The elevation of the site ranges from 500 to 2100 m. The mean annual precipitation is 500–600 mm, with the lowest values in July and August. The mean forest stock growth in the study area was 282 m^3 ha^{-1}. Since 2000, the even aged management system with shelterwood cutting has been replaced with uneven-aged management system by selection cutting for these forests. The average of the utilized volume is 2500 m^3. The total length of forest roads in the study area is 36724 m.

Data collection

GIS has also developed functions such as analyzing available information and using it in a decision and support system, as well as it compiles the information as a whole and stores it. In this research road characteristics such as road density, road spacing and network percentage were measured for existing network in study area. To design a new road based on GIS, the standard topographic maps at a scale of 1:10000 were digitized and DEM were produced for the study area. The factors considered were hillside slope, hillside aspect, hydrological network, stock growth and soil type. The map layers were overlaid, analyzed and processed by using GIS software ILWIS, Arc View described below.

To provide a slope map, DEM of the study area was used. Slopes were classified into six classes (0–10, 11–30, 31–60, 61–80, 81–100, > 100% inclination). Slope direction map of study area was divided into 8 directions including north, northeast, east, south, southeast, southwest, west and northwest. Stock growth was divided into 4 classes (0–10, 100–200, 200–350, > 350 m^3 ha^{-1}). Soil was classified into stable, mid stable and unstable classes.

Any existing maps of the area should be acquired. In spite of any imperfections, these maps can be a considerable help in the initial planning stages. Slope and stock growth maps were a prerequisite to plan the forest road network. In GIS analysis, a contour map with 10 m intervals and different layers was generated based on a topographic map with 1:10000 scales.

GIS is used since it is becoming the mainstream tool in forest road network alignment and location analysis. It is also proved to be beneficial in helping forest managers to evaluate alternatives and select the optimal location for forest-road network. Theoretical parts of these applications are discussed briefly with emphasis on the general procedure for locating forest roads (Tucek, Pacola 1999).

To offer the appropriate variant with respect to the environmental and forest road construction principles, the most effective factors in path finding were identified in the study area. Then, by overlaying slope, aspect, stock growth and soil type layers, the suitable map of regions for selecting routes was achieved.

Many road-location alternatives were analyzed using PEGGER. PEGGER is designed as a preliminary route location tool that can inform a more detailed analysis. Grade changes can be accomplished by using the roads drop-down menu, using the PEGGER toolbar. Each of road variants was evaluated according to the following equation:

$$DV = \sum_{i=1}^{n} (D_i \times V_i), \quad (1)$$

where DV is the ton per kilometer, D_i is the distance between each point of the grid and the unloading area in kilometers; V_i is the trees volume per hectare in each of grid points and n is number of points on grid (Fig. 1).

The access roads are the uniform system of network of transport ways, which serves the purposes of forest management. The success of an automatic road network layout over steep terrain mainly depends on the model design. In steep terrain, where a road must accommodate considerable differences in elevation, a shortest path algorithm is used on a grid (Stückelberger 2008). Fig. 2 shows the procedure of GIS based planning of forest road network and skid trail.

The offered forest road network was compared with existing network using following equation:

$$E = \frac{S_A}{A} \times 100, \quad (2)$$

where E is networking percentage, A is total area (ha) and S_A is skidding area (ha).

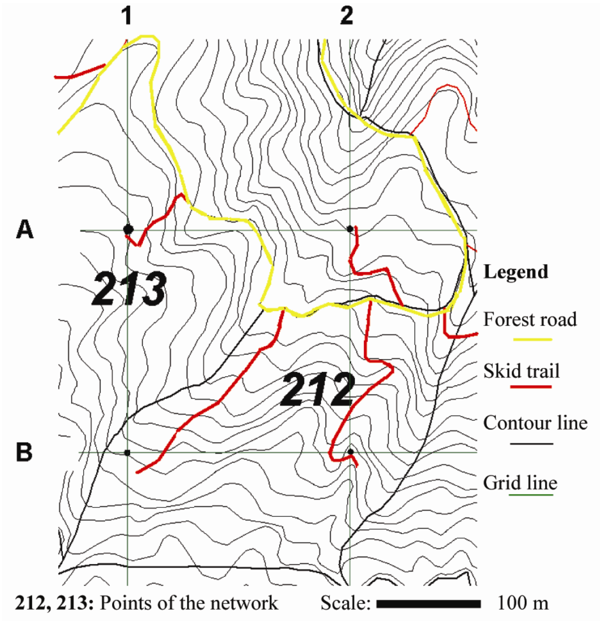

Fig. 1. Minimum distance of skidding in grid points to road

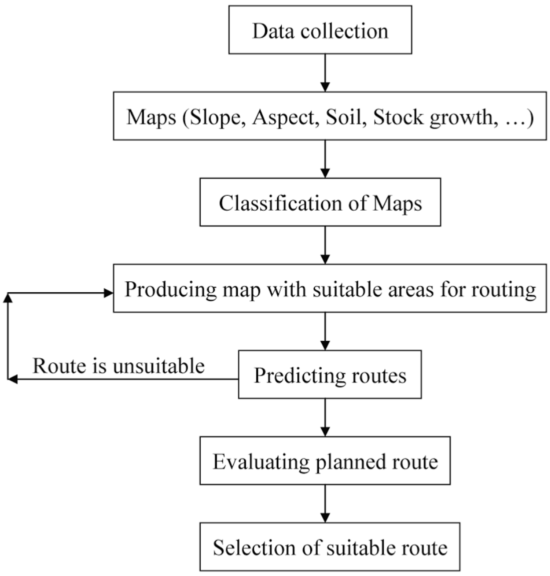

Fig. 2. Simplified flow diagram of the forest road network planning in GIS

3. Results and discussion

Hillside slope classes

When the roads are constructed in mountainous terrain, the excavated materials from hillside are widely scattered downward the slope (Kim *et al.* 2004). In the slope map, the slope class 31–60% predominated with the total area 1896.92 ha, while the slope class had the lowest cover in the study area (Fig. 3).

The new road network density modeled using GIS had shorter skid trails with more skid trails and decreased primary transportation cost. The newly planned roads and skid trails passed on suitable slopes, and created suitable road coverage in comparison between two road networks (Current, by GIS) in the study area (Fig. 4).

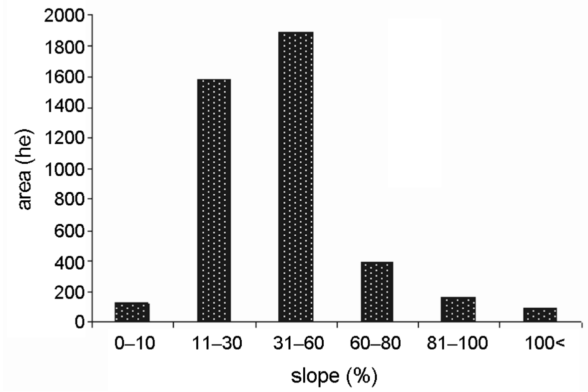

Fig. 3. Slope distribution for each class in the study area

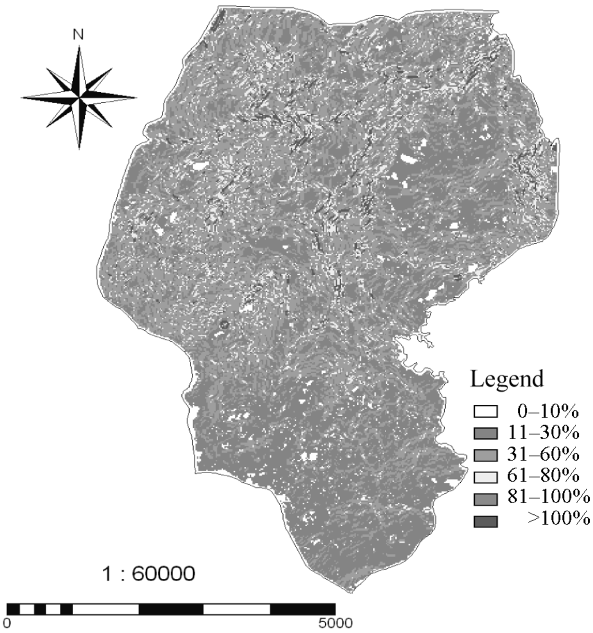

Fig. 4. The slope map of the study area

Fig. 3 shows that 85% of total area was represented by areas with slope steepness less than 60%. Comparison of existing and designed forest road showed that the new road with more density (10.87 m ha^{-1}) and shorter length for skid trails (81.04 km) helps the forest manager to decrease the destruction of forest (Eghtesadi *et al.* 2002). In a long-term perspective, forest road planning using GIS is an appropriate tool to implement a sustainable forest management.

Properly locating a road depends on the type of road, geology, land use, hydrological network and the side slope of the ground. The clearing limit of roads and skid trails will vary, depending on ground slope and the amount of cut and fill required (Kramer 2001; Misir, Baskent 2002). Intensive weathering produces deep laterite profiles that occur on flat slopes in the terrain where the run-off is limited. The slopes of embankments and cuttings must be adapted to the soil properties, topography and importance of the road.

Hillside aspect classes

According to the prepared map, all aspects were present in the study area (Fig. 5). The largest areas of slopes are inclined in southwest, northwest and northeast directions, while the least areas are inclined toward the southeast (Fig. 6). A road along the slope which gets the most sun will dry out faster after rain. Consequently, it will be subject to less damage from traffic and will result in lower maintenance cost (Sessions 2007).

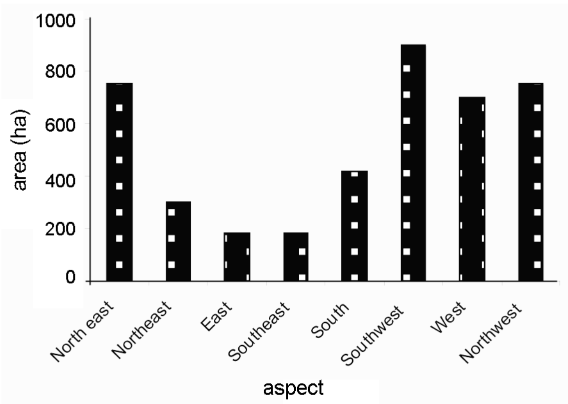

Fig. 5. Aspect distribution for each class

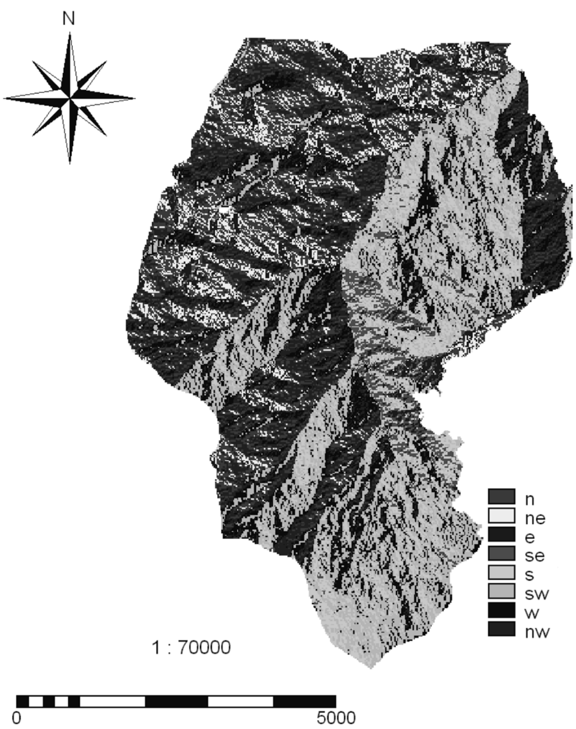

Fig. 6. Aspect map of the study area

The southern and western parts of study area are characterized by low rainfall, high wind speed, intense solar radiation, and high potential evapotranspiration. High rainfall and poor solar radiation is occurred in northern and eastern aspects. So, the roads which established in these directions may be damaged by runoff and water concentration on road surfaces.

Soil stability classes

The stability of soil and rock is mainly dependent upon geological characteristics such as discontinuities in rock mass (Kim *et al.* 2004). The map soil stability showed that most of the study area had stable soil (Fig. 7). Stable soil plays a vital role in routing of the forest road. Also in GIS designed road network more of the roads pass through high stable soil area (Fig. 8).

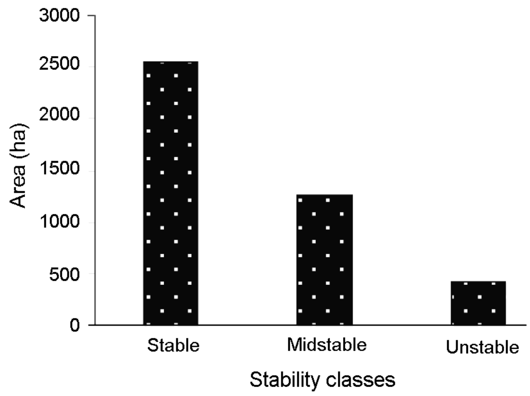

Fig. 7. Soil stability distribution for each class

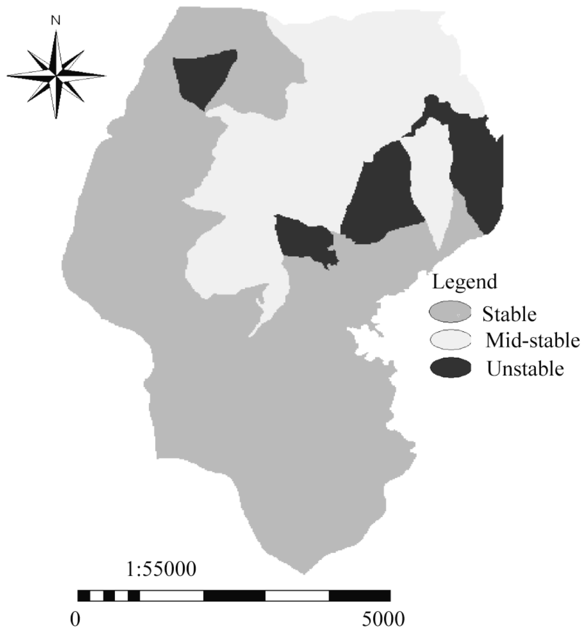

Fig. 8. Map of soil stability in the study area

Soil and terrain conditions are determined according to type of rock, soil moisture, and surface water and soil as a construction material (Petkuvienė, Paliulis 2009). Soils in roadside forest ecotone zones constitute a certain filter buffering chemical contamination generated by motor traffic. Both the soil and roadside plant cover cumulate chemical pollutants and restrict their migration to the forest environment (Poszyler-Adamska, Czerniak 2007) (Table 1).

Table 1. Classification of soil stability

Soil stability	Geology and soil properties
Stable	Thickness layer of lime, low slope, deep soil with 30–35% clay, well drainage
Mid-stable	Thickness layer of lime, shale lime, mid slope with loose soil, medium drainage
Unstable	Sand stone, silt stone, steep slope with loose soil, bad drainage

Stock growth classes

The mean of stock growth in the study area was 282 $m^3 ha^{-1}$ (Fig. 9). Forests that have more stock growth must be near to roads. Thus, the road density is concentrated in enriched stands of forest (Fig. 10). In Hosseini *et al.* (2004) research digital maps were produced and analyzed through GIS and Arcview software.

Finally, the best area on the overlaid map to plan forest road was selected, with the effective factors taken into account. The design of the optimal forest road using GIS and Arcview software was determined and the road map was prepared. The cycle time or distance from the logging area is an important economic factor to consider in establishing a forest roads alternative.

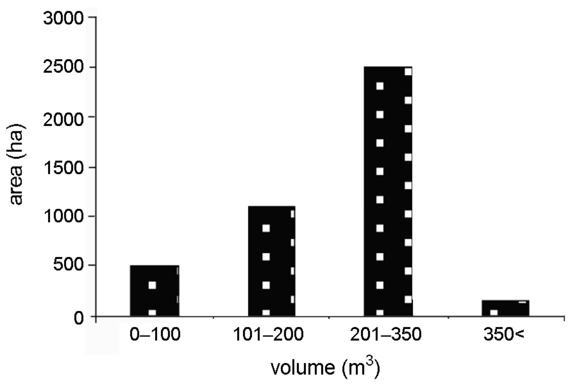

Fig. 9. Standing volume distribution for each class

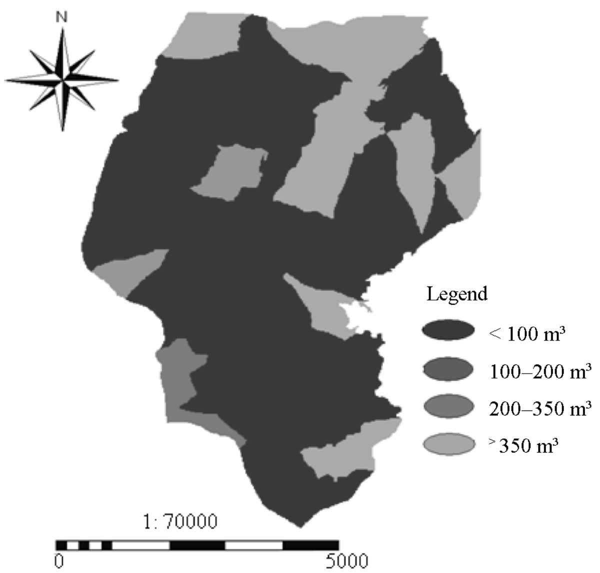

Fig. 10. Forest stock growth map of the study area

Hydrological network

Hydrological network in mountain areas is of main importance to land use planning, due importance in hazards occurrence (Fig. 11). The first parameter is the spatial location of road segments in relation to stream reaches in the study watersheds (Fig. 12).

Three hillside positions were derived: valley bottoms are defined as the area within a 100-meter flow length distance around streams; ridge tops represent the area within a 100-meter flow length distance around ridges; mid-slopes are located in the remaining area (Bernard 2006).

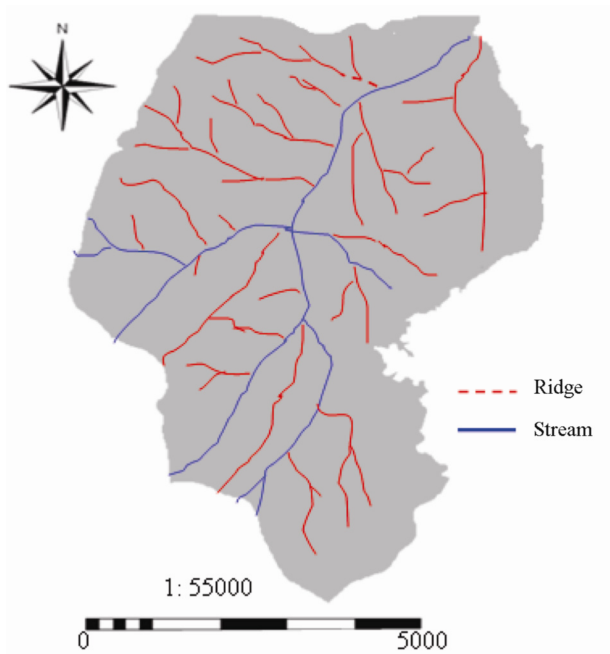

Fig. 11. Hydrological network of the study area

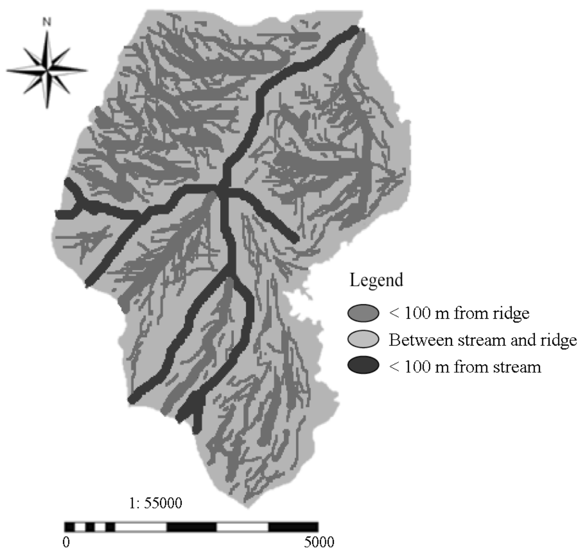

Fig. 12. Hydrological map for deriving the road spatial location

Existing and offered forest road

Existing forest road and existing skid trail conditions with offered forest road and skid trail were designed by using GIS. Compare the existing road network, the road density and road coverage increased in the new planned road.

Subsequently, the skid trail length and skid trial density were decreased. As apparent, with increasing road coverage larger areas can be left for forestry rather than roads, thus allowing higher wood production. According to networking percentage, the new road network is more cost-effective than the existing road system in the particular area; therefore it is applicable in management of this area (Fig. 13).

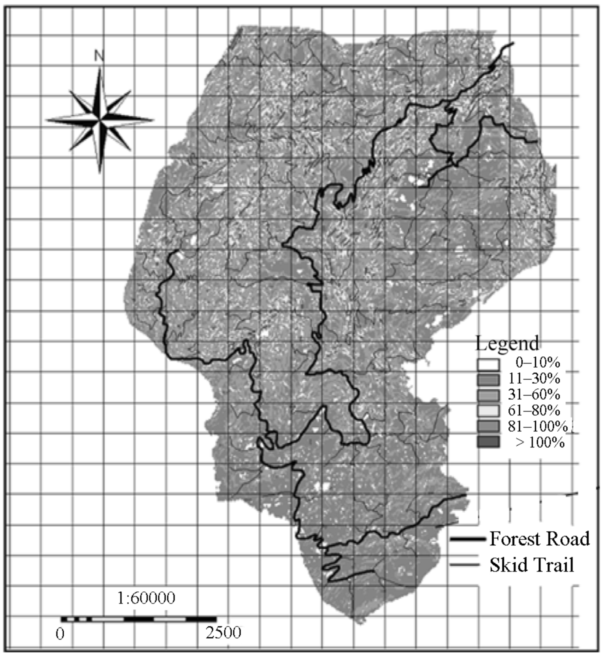

Fig. 13. Existing forest road and skid trials in GIS

In this study the existing forest road length was 36.72 km, road density was 8.68 m ha^{-1}, and skid trail length was 98.062 km, skid trail density was 23.17 m ha^{-1}, and coverage of road and skid trails was 54% of the study area (Table 2). It seems that road and skid trial length and density are not sufficient for the particular area. Therefore, it was impossible to access all forest lands throughout the area (Fig. 14).

Table 2. Comparison of existing road and the offered road.

Road type	Forest road			Skid trail	
	Length (km)	Density (m ha^{-1})	Cover (%)	Density (m ha^{-1})	Cover (%)
Existing	36.74	8.68	54	98.06	23.17
Offered	47.23	10.87	79	81.04	19.15

The existing road network was sparse, and the number of skid trails was low, but length of each one was more than standard, according to Sunberg's (1985) findings in the USA, thus causing increased winching and skidding costs. Additionally, in constructing forest roads, forest surface and adjacent landscape along the roadway are mostly displaced due to removal of soil and vegetation cover, which then results in serious environmental impacts such as soil erosion and sediment yield to streams (McClelland *et al*. 1999; Heralt 2002).

By designing the new routes the opened areas of forests were increased from 54% to 79%. The new forest roads and skid trails have been shown in Fig. 15. In most regions that support forest activities, such as harvesting and silvicultural practices, roads are the backbone of efficient management (Stückelberger 2008).

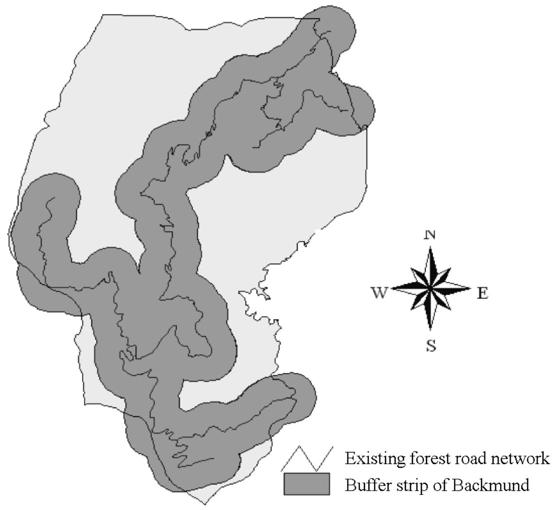

Fig. 14. Opened areas by existing forest road

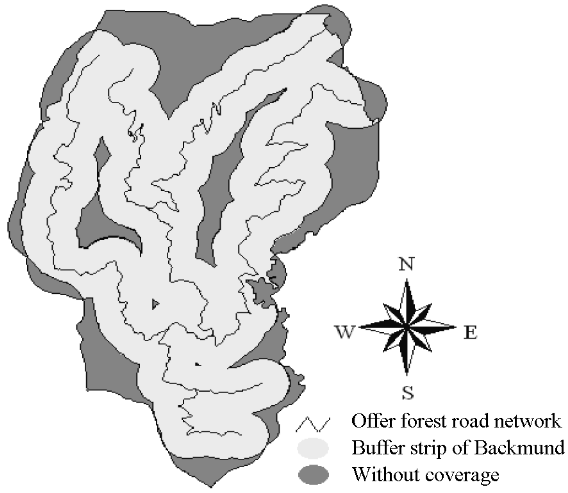

Fig. 15. Opened areas by offered forest road

According to our results, the unsuitable coverage, length and density of existing forest road network confirms the necessity for a suitable assessment of a new plan for forest roads and skid trails that would increase the access to the forest in the study area. The coverage of newly planned forest road network was estimated to be 79.18%, its total length was 47.23 km and road density was 10.87 m ha^{-1}. The skid trial length and its density were estimated as 81.04 km and 19.15 m ha^{-1}, respectively (Table 2).

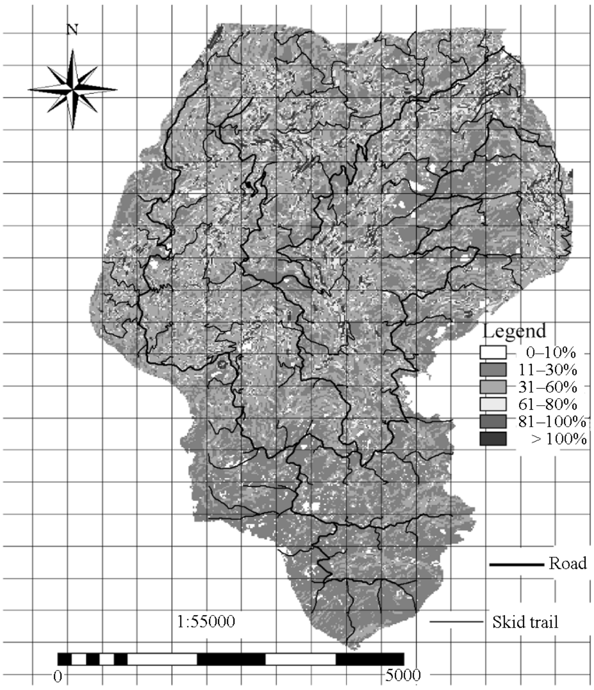

Fig. 16. New offered forest road and skid trails by GIS

The relative openness existing forest road is analyzed by the use of a computer on maps of the study area in digital form as a basis, for which the program Arc-GIS is used (Fig. 16). Road network planning is a crucial activity that should strive for optimal solutions. Tools for automatic road network design improved simultaneously with advancements in computing performance and the emerging availability of digital terrain data (Stückelberger 2008).

The rural road network planning methodology was presented in Singh (2010) research paper based on accessibility concept and implemented using GIS technology. A new index of accessibility is designed which evaluates various rural road link options for their efficiency in accessing the missing functions in the unconnected settlement.

The accessibility based approach of rural road planning offers maximum benefit to the unconnected settlement in terms of access to various facilities or the main road network in a coordinated fashion by maintaining an integrated road system. A GIS-based technique for the analysis of alignment of new road link options has been developed which considers the topographic and land use characteristics of the area. GIS-T software package, TransCAD, is used to organize the database for road alignment and implementation of the developed rural road planning methodology (Singh 2010).

4. Conclusions

Satellite data are suitable instruments to introduce and classify forest places when integrating the parameter slope, aspect, stock growth and forest soil stability. The integration of this satellite data into GIS can be very useful to determine optimal road density and to decrease forestry management cost.

One tool that has considerable potential for supporting road and ultimately planning is GIS. A transportation system (such as a system of forest roads and skid trails) may be described as a network, a collection of interconnected segments or links. Each link describes a unique path between two adjacent nodes.

The maps of hillside slope, hillside aspect or direction, hydrological network, soil and volume of tree per hectare were prepared and classified. Maps were overlaid to obtain ecological capability units. These units were arranged in tables to divide the research area into different units for road selection.

In this study the total length of existing forest road was 36.745 km and the forest road coverage was 54%. The suggested road network length measured using GIS was 47.23 km and forest road density was 10.87 m ha^{-1}, with 79% coverage. On the basis of GIS measurements, the skid trails on new forest road network system had shorter length and more frequency. This decreases primary transportation cost, to pass on the suitable slope and created suitable coverage for accessibility to forest.

Increasingly, hard-copy maps are often converted into a digital format by scanning and can be accessed and analyzed through GIS. The GIS software promotes the effective analysis of collected data and supports the digital mapping for example the projecting of the grade lines.

This paper presented GIS models for mapping the spatial variability of different objective functions in forest road design. The results of the analysis of the existing forest road network showed that it is necessary to design and build new roads for opening of unopened areas.

Acknowledgements

The authors wish to thank the Sari Agricultural Sciences and Natural Resources University for a research grant in support of this project. Moreover, the authors wish to thank the helpful comments from two anonymous reviewers, whose remarks and indications significantly improved the original manuscript.

References

Abdi, E.; Majnounian, B.; Darvishsefat, A.; Mashayekhi, Z.; Sessions, J. 2009. A GIS-MCE based model for forest road planning, *Journal of Forest Science* 55(4): 171–176.

Akay, A. E. 2006. Minimizing total costs of forest roads with computer-aided design model, *Academic Processing Engineering Science (SADHANA)* 31(5): 621–633.

Akay, A. E.; Sessions, J. 2005. Applying the decision support system, TRACER, to forest road design, *Western Journal of Applied Forestry* 20(3): 184–191.

Anderson, A. E.; Nelson, J. 2004. Projecting vector based road networks with shortest path algorithm, *Canadian Journal of Forest Research* 34(7): 1444–1457. doi:10.1139/x04-030

Ariel, E.; Lugo, H. G. 2000. Function, effects, and management of forest roads, appropriately, *Forest Ecology and Management* 133: 249–262. http://dx.doi.org/10.1016/S0378-1127(99)00237-6

Aruga, K. 2005. Tabu search optimization of horizontal and vertical alignments of forest roads, *Journal of Forest Research* 10: 275–284. http://dx.doi.org/10.1007/s10310-004-0136-5

Babapour, R.; Naghdi, R.; Salehi, A. 2006. The importance of GIS in forest roads planning (Case study, Shafarood catchment), in *GIS conference, ITC scientific society*, 663–668.

Bernard, A. M. 2006. *Geospatial modeling of forest road networks and their effects on stream macro-invertebrate communities*. Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science in Forestry. 118 p.

Cole, D. N.; Landres, P. B. 1996. Threats to wilderness ecosystems: impacts and research needs, *Ecology Application* 6: 168–184. http://dx.doi.org/10.2307/2269562

Dean, J. D. 1997. Finding optimal routes for networks of harvest diet access roads using GIS-based techniques, *Canadian Journal of Forest Research* 27: 11–22. http://dx.doi.org/10.1139/x96-144

Demir, M.; Ozturk, T. 2004. A research on forest road planning and projecting by inroads software in bolu region of Turkey, *American Journal of Applied Science* 1(4): 295–301. http://dx.doi.org/10.3844/ajassp.2004.295.301

Eghtesadi, A.; Sobhani, H.; Rafatnia, N. 2002. Study of timber transportation in the Vaz research forest, *Iranian Journal of Research and Construction* 12(2): 23–34.

Freycon, V. 1999. Data management and modeling using remote sensing and GIS for tropical forest land inventory, in *Proceedings of the FIMP-INTAG International conference*. October, Jakarta, Indonesia. Jakarta, 26–29.

Ghaffarian, M. R.; Sobhani, H. 2007. Optimization of an existing forest road network using Network 2000, *Croatian Journal of Forest Engineering* 28(2): 185–193.

Ghaffarian, M. R.; Sobhani, H. 2008. Optimum road spacing of ground based skidding operations in Nowshahr, Iran, *Caspian Journal of Environment Science* 6(2): 105–112.

Heralt, L. 2002. Using the road system to design an optimum forest road variant aimed at the minimization of negative impacts on the natural environment, *Journal of Forest Science* 48(8): 361–365.

Hosseini, S. A.; Sarikhani, N.; Soleimani, K.; Jalali, S. G.; Hosseini, S. M. 2004. An investigation of effective factors in forest road selection using GIS (a case study in Nowshahr-Mazandaran Province), *Iranian Journal of Nature Resaearch* 57(1): 59–75.

Kim, K.; Park, H.; Lee, S.; Woo, I. 2004. Geographic Information System (GIS) based stability analysis of rock cut slopes, *Geosciences Journal* 8(4): 391–400. http://dx.doi.org/10.1007/BF02910475

Kramer, B. W. 2001. Forest Road Contracting, *Construction and Maintenance for Small Forest Woodland Owners* 35: 52–79. Oregon State University, College of Forestry.

Misir, M.; Baskent, Z. 2002. The role of GIS in multi-objective forest planning, in *International symposium on GIS*, September 23–26, Istanbul. Turkey.

Murat, D.; Tolga, O. 2004. A research on forest road planning and projecting by inroads software in a region of Turkey, *American Journal of Applied Science* 1(4): 295–301. http://dx.doi.org/10.3844/ajassp.2004.295.301

McClelland, D. E.; Foltz, R. B.; Falter, C. M.; Wilson, W. D.; Cundy, T.; Schuster, R. L.; Saurbier, J.; Rabe, C.; Heinemann, R. 1999. Relative effects on a low–volume road system of landslides resulting from episodic storms in Northern Idaho, in *7th International Conference on Low – Volume Roads*, Washington 2: 235–243.

Naghdi, R.; Bagheri, I.; GhaJar, E.; Taheri, K.; Hasanzad, I. 2008. Planning the most appropriate forest road network considering soil drainage and stability using GIS in Shafaroud Watershed-Guilin, in *Conference Proceedings*: Map Asia 2008, India. 10 p.

Najafi, A.; Sobhani, H.; Saeed, A.; Makhdum, M.; Mohajer, M. M. 2008. Planning and assessment of alternative forest road and skidding networks, *Croatian Journal of Forest Engineering* 29(1): 63–73.

Pentek, T.; Pičman, D.; Potočnik, I.; Dvorščak, P.; Nevečerel, H. 2005. Analysis of an existing forest road network, *Croatian Journal of Forest Engineering* 26(1): 39–50.

Petkuvienė, J.; Paliulis, D. 2009. Experimental research of road maintenance salts and molasses ("Safecote") corrosive impact on metals, *Journal of Environmental Engineering and Landscape Management* 17(4): 236–243. http://dx.doi.org/10.3846/1648-6897.2009.17.236-243

Poszyler-Adamska, A.; Czerniak, A. 2007. Biological and chemical indication of roadside ecotone zones, *Journal of Environmental Engineering and Landscape Management* 15(2): 113–118.

Rafetnia, N.; Abdi, O.; Shataei, S. 2006. Determining proper method of preliminary forecasting of mountain and forest roads using GIS, *Iranian Journal of Forest and Poplar Research* 14(3): 245–257.

Sessions, J. 2007. *Forest Road Operations in the Tropics*. Springer-Verlag, Berlin, Heidelberg, New York. ISBN-10 3-540-46392-5. 170 p.

Singh, A. K. 2010. GIS based rural road network planning for developing countries, *Journal of Transportation Engineering* 136(8): 115–124.

Sobhani, H.; Naiaj Nouri, S. 2006. Guide direction for placing of decking and skid trial, *Iranian Forest and Range Lands Organization*. 45 p.

Sundberg, U. 1985. Distribution of the costs of joints forest roads according to crosswise and lengthwise road functions, *Studia Forestalia Suecica*. 25 p.

Stückelberger, J. A. 2008. *A Weighted-Graph Optimization Approach for Automatic Location of Forest Road Networks*. ISBN 978-3-7281-3217-8. 127 p.

Tucek, J.; Pacola, E. 1999. Algorithms for skidding distance modelling on a raster digital terrain model, *Journal of Forest Engineering* 10(l): 67–79.

Williams, T. 1998. The unkindest cuts, *Audubon* (January–February): 24–31.

OPTIMALIŲ MIŠKO KELIŲ TINKLO PROJEKTAVIMAS ĮVERTINUS POVEIKĮ APLINKAI GIS PROGRAMA

S. A. Hosseini, M. R. Mazrae, M. Lotfalian, A. Parsakhoo

Santrauka

Miško kelių tinklo planavimas – viena svarstomų problemų, siekiant užtikrinti tvarią miškotvarkos sistemą šiaurinėje Irano dalyje esančiuose miškuose. Šiame straipsnyje pristatomas miško kelių planavimo techninis metodas, taikant GIS (geografinės informacinės sistemos) programą ir naudojant Vatan miško, Golestan provincijoje, Irane, planus. Šio tyrimo tikslas – išsiaiškinti galimybes, kaip optimizuoti miško keliukų ilgį ir sumažinti neigiamą poveikį miškui, mažinant perteklinį šių keliukų trasos ilgį. Pirminiai rezultatai parodė, kad bendras esamų kelių ilgis siekia 36 745 km, kelių tinklas aprėpė 54 % visos tiriamosios teritorijos, tankis siekė 8,68 m ha^{-1}, o optimalus miško kelių tinklas buvo rengiamas pagal esamą 98,06 km ilgio miško keliukų tinklą, kurio tankis – 23,17 m ha^{-1}. Bendras siūlomo kelių tinklo ilgis siekia 47,23 km, tankumas – 10,87 m ha^{-1}, jis aprėpia 79 % teritorijos. Miško keliukų ilgis – 81,04 km, tankumas – 19,15 m·ha^{-1}. Remiantis GIS matavimais, naujo miško keliukų tinklo keliukai buvo trumpesni, tačiau jų tinklas tankesnis. Dėl šios priežasties mažėja pirminės transporto išlaidos ir sukuriama optimali miško keliukų aprėptis, pagerinamas prieinamumas.

Reikšminiai žodžiai: kelių tinklas, miško kelias, optimizavimo technika, geografinės informacinės sistemos, Vatan miškas, Iranas.

ПРОЕКТИРОВАНИЕ ОПТИМАЛЬНОЙ СЕТИ ЛЕСНЫХ ДОРОГ С УЧЕТОМ ВОЗДЕЙСТВИЯ НА ОКРУЖАЮЩУЮ СРЕДУ, ОЦЕНЕННОГО С ИСПОЛЬЗОВАНИЕМ ГИС

С. А. Госсейни, М. Р. Мазрае, М. Лотфалян, А. Парсакхоо

Резюме

Планирование сети лесных дорог является одним из важнейших вопросов при создании упорядоченной системы лесохозяйствования в северной части Ирана. В статье представлен технический метод планирования лесохозяйственной деятельности (прокладки дорог) с использованием ГИС и плана леса Ватан в провинции Гулистан Ирана. Целью исследования было выяснить возможности оптимизации длины лесных дорог и уменьшения негативных последствий их избыточной длины. Результаты исследования показали, что общая протяженность существующих лесных дорог составляет 36 745 км, сеть дорог охватывает 54% всей исследованной территории, ее плотность – 8,68 м $га^{-1}$. Оптимальная сеть лесных дорог создавалась на основании имеющейся сети лесных дорог, протяженность которой 98,06 км, плотность – 23,17 м $га^{-1}$. Протяженность предлагаемой сети дорог составит 47,23 км, плотность – 10,87 м $га^{-1}$, она охватит 79% территории. Длина лесных дорог составит 81,04 км, а плотность – 19,15 м·$га^{-1}$. На основании измерений, проведенных с использованием ГИС, длина дорог лесной сети стала короче, а сеть более густой. В связи с этим снижаются первичные затраты на транспорт, охват лесными дорогами становится более оптимальным, увеличивается доступность.

Ключевые слова: дорожная сеть, лесная дорога, техника оптимизации, географическая информационная система, лес Ватан, Иран.

Seyed Ataollah HOSSEINI. PhD, Associate Professor, Dept of Forestry, Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Iran. Research interests: forest road network planning, bioengineering, forest road construction. Author of several research papers about forest engineering.

Mohammad Reza MAZRAE. MSc graduate student of forestry, Dept of Forestry, Faculty of Natural Resources, Mazandaran University, Sari, Iran. Research interests: forestry, geographical information system.

Majid LOTFALIAN. PhD, Associate Professor, Dept of Forestry, Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Iran. Research interests: forest transportation, timber harvesting, skid trail planning, logging damage. Author of several research papers about forest engineering.

Aidin PARSAKHOO. PhD student of forest engineering, Dept of Forestry, Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Sari, Iran. Research interests: forest road network planning, forest road construction and maintenance, runoff and sedimentation from forest road, bioengineering, forest utilization, timber harvesting, skidding. Author of more than 40 technical and research papers on forest engineering.