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Forest Road Network Design based on Economic and Environmental Criteria with Weighting the Indices using PEGGER Software

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A B S T R A C T

Objective: Roads in the forest have several tasks and costly road construction has led the designers to design the best network.
Methods: For this purpose, data layers (slope, direction, forest type, etc.) were prepared and multi-criteria evaluation method of these characteristics was used for preparing suitable plan such that after the classification and valuation of inner layers of maps, Pairwise comparison method in Analytic Hierarchy Process (AHP) was used for weighting the characteristics and a compilation of experts opinions which was designed into questionnaires, entered in the process and using Expert Choice software, the importance coefficient of each layer was obtained.
Results: Weights of factors, characteristics, and restrictions was imported on multi-criteria evaluation model and the combination of characteristics and overlapping the layers according to their importance factor was performed based on multi-criteria evaluation model.
Conclusion: Option 6 were individuated as the most desirable option because of the minimum amount of multiplying the road length in total distance of skidding and the insignificant difference in soil operation volume.

1. Introduction

Forest roads, like public roads, play different roles and roles in most of the forestry and other forestry activities, the impact of which is undeniable. Forest use must be carried out in a way that ensures reasonable and sustainable use of its products, as well as the survival of the forest and its continuous production. Forestry plans are designed to sustainably manage forest protection and exploit its products and services. In this regard, forest road networks, as infrastructures, play an essential role in organizing, operating, transporting and protecting and maintaining the area. Forest roads, on the other hand, are highly sensitive to economic, environmental and public opinion due to the heavy costs associated with design, construction, and negative impacts on the environment and wildlife(Abdi etal.,2008). Choosing the path appropriate to the objectives of the forestry plan, ecological potential of the forest areas, etc., by GIS, which is a useful tool in this regard, can easily and accurately meet the

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designer's goals. It is used in various fields including urban and regional planning, geology and mines, agriculture and natural resources, etc. and is capable of improving management and planning. This knowledge will accelerate the planning process in identifying critical cases and so on (Akay etal.,2004; Stückelberger etal., 2006).

comparing the designed roads using the facilities of GIS with forestry plan roads, it was concluded that the road designed by GIS are technically and environmentally more suitable than forestry project roads (Chung ,2004; Rackely,2008). Another study using GIS addressed with the length of main road and skid trail, networking percent and skidding distance and the length of area public roads and considered it as an appropriate tool in design(Hasanzadeh, 2009).

Multi-criteria evaluation is a method for comparing the importance of different layers relative to each other and integration of data based on their importance in decision making. In this regard, the pairwise comparison method is applied in Analytic Hierarchy Process and it has been considered as an appropriate method of weighting and a suitable framework for group decision-making(Heinrich ,2001; Dodson etal.,2007) .In another study the Analytical Hierarchy Process (AHP) was used in order to identify the priorities of road maintenance and to determine the benefits of completing the repair or upgrading a project and in the end, it was concluded that Analytical Hierarchy Process is an appropriate framework for quantitative measurement of environmental benefits and using them in modeling and scheduling algorithms (Coulter etal.,2006;Pentek etal.,2007;Stückelberger etal.,2007)Also in a study, the importance of factors such as slope, direction, elevation, type of bedrock, soil permeability and inventory of forest on road design was investigated (Firouzan, 2007).

In this study, values are seven factors of slope, geographical direction, volume per hectare, forest types, geology, soil stability, and suitable areas for depot.

2. Materials and methods

forests are located at low altitudes and northern midland profile of Alborz mountain in northwest area of Iran (Figure2).In this study, after complete investigation and review of various sources and forestry projects of series, collecting and preparing the research needed information including field observations, corresponding maps were prepared. In the study, topographic sheets files of 1: 25000 with DGN format of area were used which have been drawn by Mapping Agency. In order to study and analyze complete information about the study area, factors which are effective in the design and construction of road routes should be identified and evaluated and the maps should be prepared on the basis of specified factors. In the later stages for making the map usable, first all the maps were scanned and then became georeferenced with GPS data and digitization process of maps was conducted.

Determining the coordinates of positive (terrace, schools, etc.) and negative (springs, slippery points, etc.), slope, geographical direction, volume per hectare, forest types, geology, soil stability, and suitable information areas were identified and maps of interest were prepared in the form of information layers.

For a better analysis on different information layers, the valuation of each information layer should be performed. For this purpose, with regard to the study habitat, first a questionnaire were prepared and given to expert contributors. For this purpose, the numerical values of information layers were valued from 1 to 9. Also according to the type of information layers in valuation, number 1 represents the lowest value and number 9 represents the highest value and average values were classified between numbers 1 and 9 (Huang et al., 2003).

2.1. Providing suitable plan (final map)

In order to incorporate the restrictions and specifications, various parameters based on their importance in decision-making and integration of data were compared. The most common multi-criteria evaluation method is linear weighting method and is one of the weighting techniques of pairwise comparison method (Murthy ,2003) . first the calculated importance coefficient in the process of multi-criteria evaluation and by using EC (Expert Choice) software in the corresponding information layers (the value of every map cell and their internal layers) was included by Arc GIS software and by integrating with restrictions, the final suitable plan was obtained that its values domain is equal to the domain in which characteristics are standardized (domain of maps internal classes). Thus weighted maps were combined and eventually the final suitable plan was obtained. Then, given that in design of road network we should not cross of some areas, such as springs, rocks, falling and drift points, mines, very high slopes and generally the negative compulsory points, a layer called restriction layer (friction map) was created. In fact, friction map is a map which cells have the lowest suitability and in which the value of each cell shows the amount of prevention in a route crossing.

2.2. Layers Classification

To be able to influence the value of each layer in final suitable plan, in GIS with classification operation, the information layer should be drawn on the basis of new values; this means that instead of classes, we select the numerical values of each layer. If the information layer is vector, we first turn it to raster then import the value of each layer in the same layer information table and new maps will be created on the basis of the values. The prepared final map, according to its value domain range was classified into five categories and encoded.

2.3. Designing the route

In order to principled design of road and taking into account the technical and economic considerations; the final overplayed map was used in which the passing priorities are marked by color and number. In this map number 1 which is marked in red is the lowest value or in other words, the worst points to pass and respectively, number 2 is in brown, ..., and number 9 with dark green has the best value. According to the overlapping map (suitable plan) we removed the contour lines files from AutoCAD software compass thread for a gradient of 10% and ..., and drawn circles to its extent in AutoCAD and then entered the circles on contour lines from which the route must cross.

2.4. Environmental assessment of designed variants

At this stage in order to minimize and reduce further damages of roads to forest and environment, after preparing final map and dividing it into five classes and designing different variants with respect to passing the optimal values of map (green areas), it was necessary to environmentally compare different variants so that the road that passes through the highest values will be the path which possess the least environmental damages.

2.5. Economic evaluation of options

2.5.1. Calculating the volume of soil operation

Of the most important factors in the finished cost of forest roads is the total volume of soil operation, including cut and fill. Given the difference of slope dip in different parts of constructed routes, on average, the standard cross sections were prepared and the exact volume of cut and fill operations is determined. For obtaining the average width of the road space using Autodesk Land Desktop 2007 software and its annexes (Autodesk Civil Design v2007), first, the connector line of road is placed on topography layer and then by giving the road information such as road space width, road shoulder width and roadway width and calculating and drawing circles arc, the routes (line) were developed. Also, the road longitudinal profile was prepared in Autodesk Land Desktop 2007 software by choosing 3 paths for each route followed by preparing the project line.

2.5.2. Technical evaluation in terms of the nearest distance criterion

In next priority, to determine that designed routes are observed necessary principles and standards in road design in terms of technical criteria, each of the variants were evaluated and compared in terms of the nearest distance from the road criteria. In this method, first in GIS environment the nearest distance of each cell from the coverage area to the road for each variant was obtained with respect to the identical cells dimensions for all variants. Each variant, for which this number is smaller, is the best in terms of opening, expansion and dispersion capabilities at the area level.

3. Results

3.1. Multi-criteria evaluation

Results of calculating characteristics weights are shown in Figure 1 based on expert opinion. Using this method, the consistency index was equal to 0.07 which given that this amount is less than 0.1, so there is the advantage of using obtained weight at the rest of the study process (Fig 1).

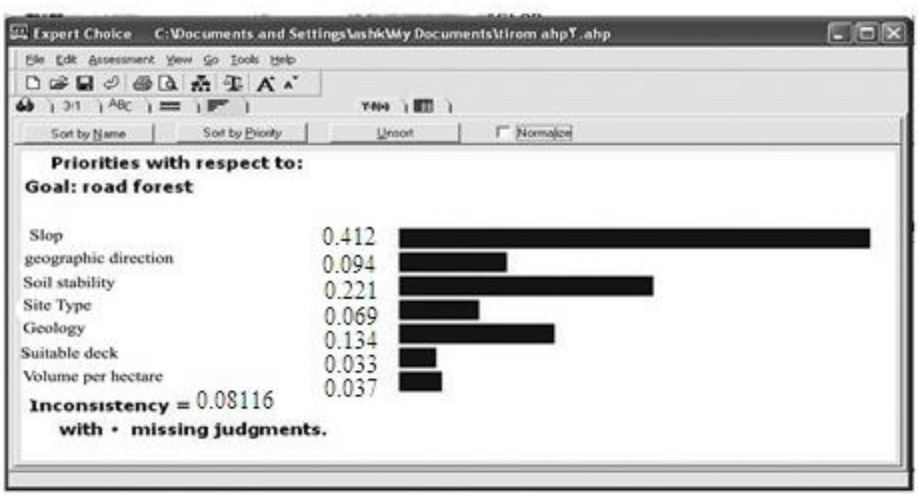


Fig. 1. The results from Multi Criteria Evaluation using EC (Expert Choice) software

3.2. The results from studying the preparation of suitable plan

In AHP extension of ARC GIS software, values of table geometric mean of opinions were and suitable plan was drawn. Based on the value domain that was given to final suitable plan, the map was divided into five categories (Fig 2, 3 and 4).

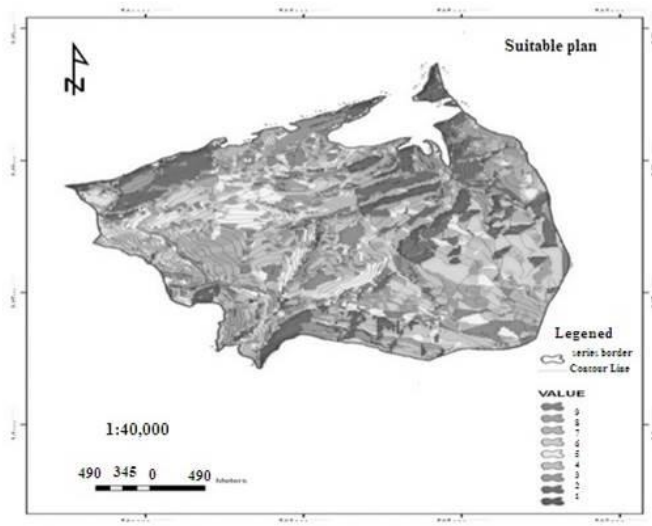


Fig. 2. Suitable plan

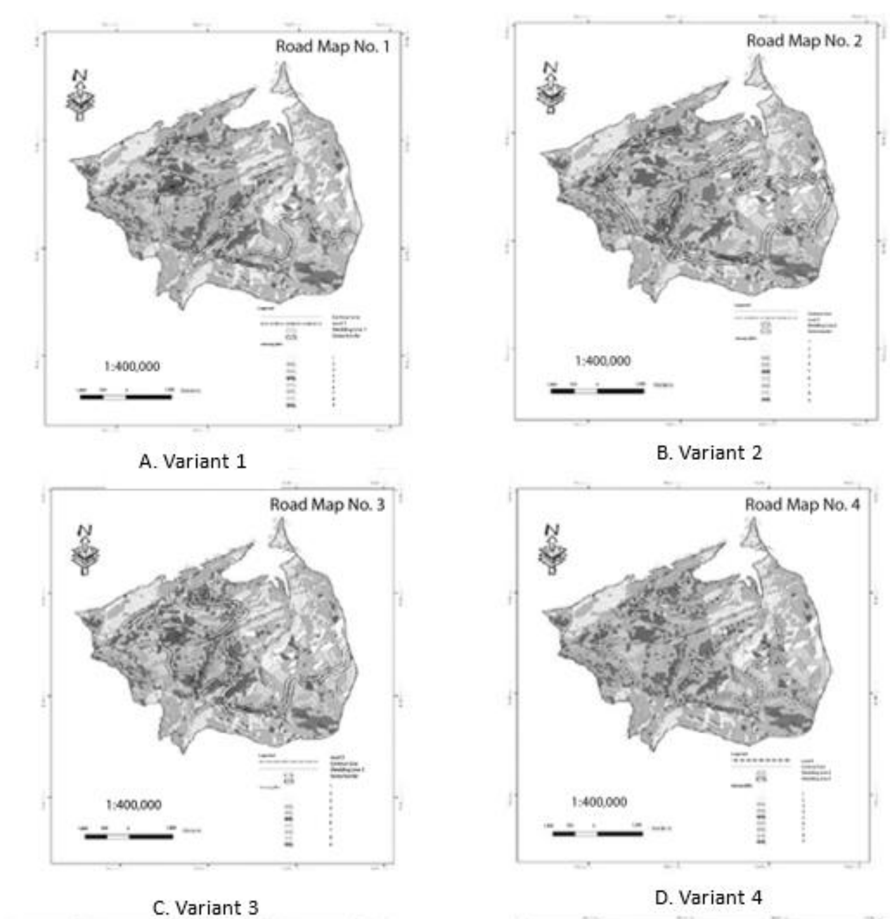
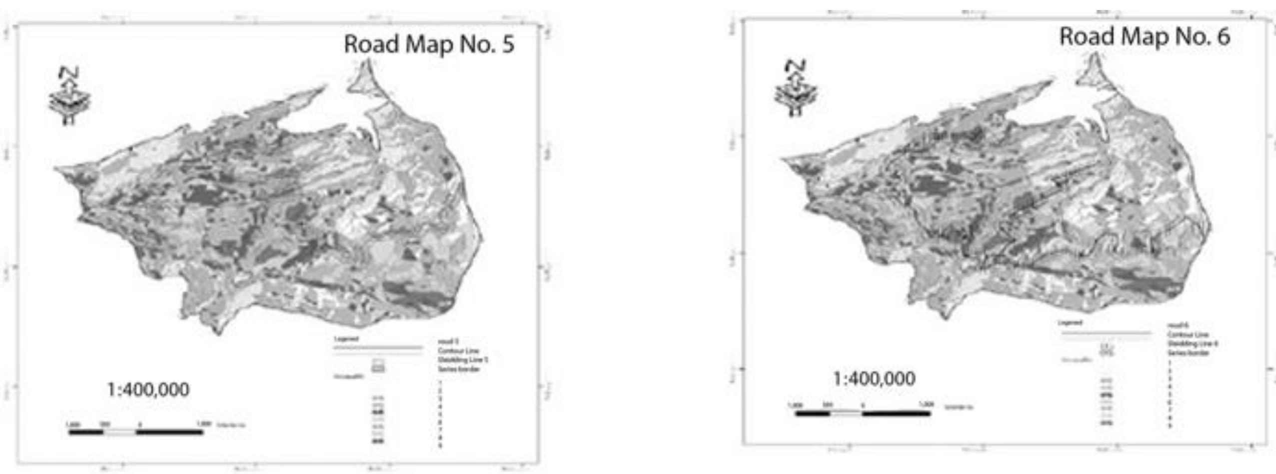


Fig. 3. Different variants of road design



E. Variant 5

F. Variant 6

Fig. 4. Different variants of road design

3.3. Environmental Assessment of Options

According to the final prepared suitable plan, and its division into five classes based on given valuation domain, the rate of designed routes passing through areas with different values was obtained considering the classification which is shown in Table (1).

Table. 1. Final results obtained from environmental assessment of variants

Variants	Total multiplication amount of route percent passing through classes with different values
1	536.61
2	455.85
3	568.96
4	606.05
5	557.43
6	565.77

According to Table. 1, variants number 4, 3 and 6 earn the most points which received technical and economic evaluation.

3.4. Calculating the volume of cut and fill and technical evaluation

One of the most important factors affecting the earth works is cut and fill which has been evaluated through software and then assessed by Sgbaden technical evaluation which results are in Table. 2.

Table. 2. Total volume of variants cut and fills

Variant Number	Road length (km)	Volume of cut operation (m3)	Volume of fill operation (m3)	The total volume of cut and fill (m3)	The mount of cut and fill per meter of road
3	17748	57483.6	56103.6	113587.2	6.4
4	20918	72667.1	71667.1	144334.2	6.9
6	16443	62311.25	61011.25	123322.5	7.5

Table. 3. Segbaden index

Variant	Road length (km)	Sum of skidding distance	Index sum of multi skidding distance and road length
Third	17.748	402.05	713488.235
Fourth	20.918	29268.93	612247.478
Sixth	16.443	32027.6	526629.827

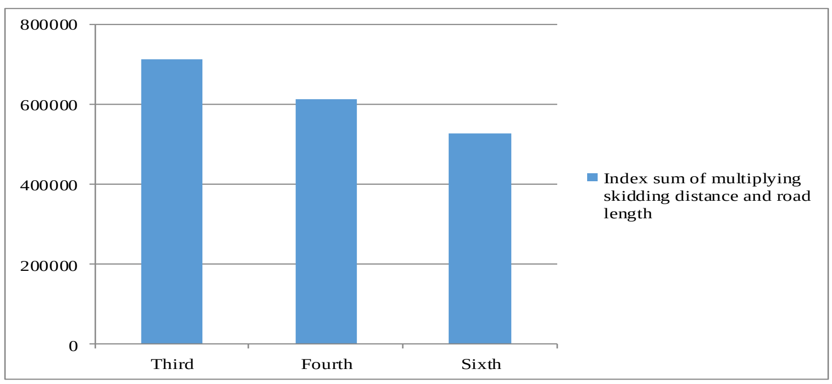


Fig. 5. Prioritizing the options based on technical standards of the nearest distance

Therefore, because of this index being low (Sgbaden criteria) for option 6, this option was known as the most desirable option and the third option was considered as the most unsuitable option (Table. 3, Fig. 5).

4. Discussion

A proper network, in addition to pursuing the main goal, can pursue other goals to some extent. Such networks can play a central role in the comprehensive management of the forest. The lack of attention to environmental issues and the mere attention to economic and forestry issues caused these projects to not meet the standards required to comply with environmental issues. In this study, environmental and economic factors were evaluated. Initially, all environmental options were evaluated and among the top three options, namely, third, fourth and sixth, were selected for technical and economic evaluation. It indicates that the fourth design of environmental considerations was more consistent. In this regard, we used pairwise comparative method in weighting of variables in hierarchical process, which was suitable for proper decision making. Abdi (2008) used a multi-criteria evaluation process to design the optimal route for their studies of road safety with minimal environmental cost for road safety with minimum security risk.. In this study, environmental, economic and technical factors were evaluated together. Among the options variant No. 4 has highest indices in terms of environmental factors which

represents that the fourth design of environmental considerations are more respected(Table2). In this regard, for weighting the variables, the pairwise comparison method was used in hierarchical process that it was suitable for making the right decisions. In a study for the road routing with the least environmental cost and for the road routing with the least security risk, multi-criteria evaluation process has been and the optimum route is designed (Murthy ,2007 ; Rogres, 2005).
They concluded that in pairwise comparison, slope has the greatest impact on the costs of road construction followed by the permeability of soil and geographical directions in the next categories. In this regard, they applied the pairwise comparison method in Analytic Hierarchy Process and considered it as an appropriate method for weighting and expressed this method as an appropriate framework for group decision-making (Raafatnia etal.,2006). According to economic and technical evaluation carried out in the three options, options 3 and 4 have the lowest and the highest volume of cut, respectively, and options 6 and 3 have the maximum and minimum of multiplying the total road length in skidding distances, respectively. Therefore, options 3 and 6 were respectively chosen as the best options in terms of economic and technical criteria observance. In designing variants No. 6, while it is approximately one kilometer shorter than variant No. 3, but the amount of earthworks volume is 1,000 cubic meters more, because the designer, in drawing the project line of this road, considered that the roof slope of cutting to be longer, or in other words, the project line height from ground is lower than the project line drawn for the third option. However, since the road construction in forest is for long-term goals, during different periods the minimum skidding distance will have a great impact in lowering the costs of operation and economically less distance between forested areas in this variant is considered as an advantage and the high cost of labor and spare parts as well as being time consuming and difficult working conditions at longer intervals, will be surely very heavy in the long term. Given that this index in the third option is about 85 thousand units higher than that in the index of option 6, and on the other hand option 6, for each meter of just earthworks is only about 17% higher, therefore, because of having the least of multiplied road length in the sum of skidding distances and the insignificant difference in the volume of earthworks, in total option 6 will be desirable. In their studies for road routing with the least environmental damage, they dealt with road routing and compared them in terms of different technical criteria to determine the optimal route.
In algorithmic examination, the network was discussed for transport system design in the forest. In this study, optimizing method of transport design was described and an exploitation project was modeled using a raster grid and finally, an algorithm was designed for solving the problem of optimizing the costs for work(Sarkhikhani ,2001). About the development of forestry in line with nature, in the mountainous forests of central Europe, it address the issue of the constructing forest roads and transportation methods in these areas, and emphasizes that mountain conditions make the road construction in these areas very costly and the costs of technical buildings in these areas can be very different according to the type of road and soil (Sepahvand ,2003; Murthy,2003).
Using existing tools, forest and mountain road designers can quickly analyze many of the road variants and evaluate economic and environmental conditions with the help of GIS capabilities . Finally, it is true that the design is based on technical and economic issues and then explores the strengths of the variants, but you cannot neglect the environmental state in which the road is to be designed. Examined as much as possible.

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