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# Planning road network in mountain forests using GIS and Analytic Hierarchical Process (AHP)

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## ABSTRACT

Forest road construction is the most costly operation in forestry. Road designing and construction in unsuitable areas may increase construction and maintenance costs and also cause many environmental impacts. Therefore, it is required to pay more attention to forest road design. In this research, we tried to introduce an appropriate method for locating forest roads using GIS and AHP simultaneously. The most important layers in locating forest road include slope, soils type, geology, hydrographic networks, aspects, trees volume $m^3$ per hectare ,tree type and elevation maps which were determined and then by using expert thought and AHP method the study area was classified in five classes including very good, good, medium, bad and worse for forest road construction. Then two new variants were designed on the prepared AHP map: the first variant was designated using traditional method and Pegger extension was applied to design the second. Pegger Planning variant (PP_variant) had the highest efficiency in path from good and bad points of view based on AHP map. The results of this study illustrated that using AHP and GIS simultaneously can introduce an appropriate and suitable method in the forest road network planning.

**Keywords**: *forest road network, road designing, GIS, AHP, road variant, Pegger software.*

## INTRODUCTION

The Caspian Forest is located in the north of Iran. It covers the north facing slopes of the Alborz Mountain ranges and is classified as a temperate mountain forest. The majority of this forest is managed as an uneven aged forest (Naghdi et al 2008). These forests as a relict climatic forest since 2 million years ago have shown a greater necessity to be conserved as a sustainable and ancient forest (Ezzati et al, 2009). Forest roads play an important role in forest management, protection and rehabilitation in mountainous areas. Efficiency of forest harvesting depends on an appropriate forest road network (Ezzati and Najafi, 2009).

Manual road planning in mountainous forests, considering technical and environmental issues, is a difficult job. More recently, simultaneous information management with respect to the important factors in road planning and rapid assessment of the roads has been possible by using GIS capabilities (Naghdi and Babapour, 2009; Pentek et al, 2005; Gumus et al, 2007). Using of all environmental and influenced layers includes slope, soils type, geology, hydrography, aspect, and trees volume $m^3$ per hectare, tree type and elevation in forest road planning in tradition methods can create enormous data and subsequently create a complicated situation when using and decision making (Ezzati et al, 2009). For this purpose, more recently researchers have been using different methods such as linear programming method (Anderson and Nelson, 2004), fuzzy logic (Tiryana, 2005), Tabu search (Aruga, 2005), genetic algorithm (Keshtiarast et al, 2006) and using digital elevation model or DEM (Akay, 2003; Rogers, 2005) to analyse all kinds of data on forest road locating.

Naghdi and Babapour (2009) prepared the stability map using soil texture and bed rock. Their results confirmed that using stability maps, GIS and AHP can be a useful method for the planning of forest road networks in mountain areas in Iran and is preferred to previous and traditional methods. In many studies, GIS has been used to include different factors in environmental impact assessment resulting from construction of any potential variant (Ghodsipour, 2002). In the other recent studies, technical issues and observing road geometric principles have been considered (Akay et al, 2004). Hoseini (2003) planned the road network using GIS in mountain forest. He stated that using GIS based on accessibility, environmental damages, costs of construction and excavation was more suitable than the existing road network and traditional method.

Raafatnia et al (2006) in their research have discussed determining a proper method for preliminary roads in mountain forest using GIS. They classified the forest area using AHP method and used Pegger software (Rogers, 2005) to design road variant. They reported that using this software would cause to design the road better. This software is able to rapidly analyze many effective factors in designing the road. A road route can be designed carefully by utilizing this software in a GIS system and thus reduce construction costs (Rogers, 2005)

Tan (1992), in a study used geographic information system to design skid trail network and explained that some primary data includes stand productivity, volume $m^3$ per hectare and cost and other weighty layers can be provided more satisfactorily. Gerasimove et al (2008) used GIS as a supporting decision making program to design and analyse skid trail network in Russia and concluded that using GIS as a decision making system can be an efficient method for offering appropriate alternatives in forest road locating.

Rogers (2005) developed the Pegger software to automatically trace the forest roads using GIS. Pegger is a powerful tool for rapid analysis of various road variants; and acts based on the percentage of longitudinal slope of the road which is determined by the planner. Passing the roads through low to moderate slopes and areas with high level of stability, reduces the costs of excavation, earth filling, land stabilization, excavation gable roofs and earth filling, and thus reduces construction costs (Kunwoo, 1990). With regards to results of the research by Heinrich (2001) construction of adequate density of forest roads are essential for development of close to nature forest management in mountainous forests. Since the major part of road construction costs consist of constructing roads in steep slopes, the high costs of road construction in this area have negative effects on road density and decrease the forest road network density.

Since there is a close relationship between the costs of road construction and maintenance and stability characteristics (soil stability and bedrock), to reduce the cost of construction, it is necessary to locate the roads on more stable grounds (Naghdi and Babapour, 2009).

The present study has taken into account various factors including 8 kinds of maps such as slope, hydrography, geology, soil type and so on, and then used Analytical Hierarchy Process (AHP) and GIS for forest road network planning in the Caspian Forest.

**Materials and Methods**

This study was carried out in a temperate mountain forest district (District 1. Nav-Asalem) covering 2252 ha of Guilan province in northern Iran. The area is located between 48˚48'46" and 48˚52'29" (E) longitude, and 37˚37'52" and 37˚41'13" (N) latitude.

Ground skidding is the dominant method of harvesting and accounts for approximately 60% of the log volume in this forest (Naghdi et al 2008). Forest roads in this district have been designated only regarding slope (Forestry planning cahier, 2009). But in this study we used 8 layers including slope, soils type, geology, hydrographic network, aspect, and trees volume ($m^3$ per hectare), tree type and elevation which can influence forest roads and should be considered in the road network planning.

Potential map for road planning is prepared by using these layers and overlaying them. Analytic Hierarchy Process (AHP) method has been used to weight the layers and the initial data have been analyzed in Expert Choice (EC) software (Malczewski, 1999). Then the analyzed data are prepared in ArcGIS 9.2 software. Finally potential maps for road planning are prepared the steps of which are mentioned below:

A. Determination of effective layers in forest roads network planning
B. Grade the effective layers and analyze them using AHP method
C. Create and categorizing the map of affecting layers
D. Planning the forest road variants
E. Evaluation of different road variants, choosing the most appropriate forest road network and compare with existing road network (Naghdi and Babapour, 2009)

**A. Determination of effective layers in forest roads network planning**

Tree types and volume (m3 per hectare) maps were prepared using forest inventory data. Then, they were confirmed by field trips with GPS. Hydrology networks were determined by field trips with GPS. All rivers were classified into 4 classes with respect to their junction (Mahdavi, 2000), for example rivers which were classified in first class have the most junctions than others and rivers which were classified in forth class have no junction; they are the first junction for other rivers. Then by use of Digital Elevation Model (DEM), the affecting factors maps were produced. By use of DEM, slope, aspect and elevation maps were produced with respect to class importance and some constraints were implemented. Soil and geology maps were prepared using the data existing in Rasht Natural Resources Office (Forestry planning cahier, 2009) in ArcGIS 9.2 software.

**B. Grade the effective layers and analyze them using AHP method**

In the next step, using Analytical Hierarchy Process, maps were rated regarding expert judgments to determine their weight (table1). Here, every layer has a preference to another layer. For instance, slope has 7 preferences to elevation and geology has 1.35 preferences to soil.

**C. Creating and categorizing the map of affecting factors**

Decision situations to which the AHP can be applied include (Saaty, 1996):
Choice - The selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.

- Ranking - Putting a set of alternatives in order from most to least desirable
- Prioritization - Determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them
- Resource allocation- Apportioning resources among a set of alternatives
- Benchmarking - Comparing the processes in one's own organization with those of other best-of-breed organizations
- Quality management - Dealing with the multidimensional aspects of quality and quality improvement

**Table 1.** Compare the relative preference with respect to expert thoughts for forest road

| final | slope | elevate | aspect | Geo | Soil | Volume | Type | Hidro |
|---|---|---|---|---|---|---|---|---|
| slope | 1 | 7.003891 | 4.994055 | 0.694444 | 0.813953 | 3.070175 | 6.478149 | 1.237113 |
| elevate | | 1 | 0.405405 | 0.217391 | 0.25 | 0.309735 | 0.364964 | 0.208333 |
| aspect | | | 1 | 0.178571 | 0.217391 | 0.344037 | 0.836653 | 0.378788 |
| Geo | | | | 1 | 1.351351 | 1.671309 | 4.407135 | 0.728155 |
| Soil | | | | | 1 | 0.857143 | 3.191489 | 0.638298 |
| Volume | | | | | | 1 | 1.796407 | 0.285714 |
| Type | | | | | | | 1 | 0.2 |
| Hydrology | | | | | | | | 1 |

The AHP sums up all the agents together in a hierarchical decomposition of the system, which represents goals and functions in the higher classifications and structure in the lower classifications (Saaty, 1980). AHP specifies priorities for alternatives and it also assigns the criteria necessary to judge these alternatives. A variety of scales have been used to measure these criteria directly integrating of which is not feasible.

In order to utilize the AHP method, the forest engineering experts were given a questionnaire to fill; therefore, we could get the average weight for each criterion. These experts should be totally conversant with this method. Each questionnaire contained the questions related to importance and preference of each factor which have a direct impact on road designing on the stable terrains.

Each layer has an inner value (rating) which refers to their values and importance with respect to forest road (table2, 3 and 4).

were dropped because of the gradient along the first axis was longer than 4 SD units. The length of the gradient represented by axis 1 was >5 SD. Hence CCA was the appropriate ordination method to be used. Eigenvalue of the first axis of DCA was high (Eigen = 0.7292), indicating that it captured the greater proportion of the variations in species composition among stands. Significant correlations along first three axes were stronger than the higher order axes.

**Table 2.** Inner rating of 6 weighty layers

| Volume ($m^3$per hectare) | rating | Slope % | rating | Aspect | rating | Elevation (m) | rating | Geology* | rating | Soil** type | rating |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-100 | 1 | 0-10 | 9 | South | 9 | 250-750 | 9 | L1 | 9 | 1 | 9 |
| 100-200 | 4 | 10-25 | 8 | West | 7 | 750-1250 | 7 | L2 | 6 | 2 | 2 |
| 200-350 | 7 | 25-60 | 6 | East | 5 | 1250< | 5 | L3 | 1 | 3 | 5 |
| 350< | 9 | 60-80 | 4 | north | 3 | | | | | | |
| | | 80< | 1 | | | | | | | | |

*Geology layer description:
L1: Shist, Granite, Basalt. With low slope, good permeability and high stability.
L2: Sand stone, Mica, Shist. With medium slope. good permeability and high stability.
L3. Shale, Sand stone, Silt stone, Shist. With high slope. Poor permeability and low stability
**Soil type layer description:
1-The depth of soil is 55-65 cm. With low to high slope, medium permeability and medium to high stability
2- The depth of soil is about 70 cm. With high slope, poor permeability and low stability.
3. The depth of soil is 45 cm. With high slope. poor permeability and medium stability.

**Table 3.** Inner rating of tree type layers

| Tree type | rating | Tree type | rating |
|---|---|---|---|
| Beech (pure) | 9 | Hornbeam (mix) | 5 |
| Beech (mix) | 9 | Alder | 4 |
| Beech-Maple | 9 | Hornbeam-Persimmon | 3 |
| Beech-Hornbeam | 8 | Conifers plantation | 1 |
| Maple (mix) | 7 | Farm land | 1 |
| Mixture trees | 6 | | |

**Table 4.** Inner rating of rivers (valley) layer

| Rivers (valley) | Constraint (m) | rating |
|---|---|---|
| 1 (main rivers) | 0-80 | 1 |
| | 80< | 9 |
| 2 | 0-60 | 3 |
| | 60< | 9 |
| 3 | 0-40 | 5 |
| | 40< | 9 |
| 4 | 0-20 | 7 |
| | 20< | 9 |

Finally, all weighted layers were overlaid together and AHP map was provided for road planning.

**D. Planning the forest road variants**

Two variants were designed to evaluate the existing road. The first variant was designed by traditionally method. The second variant was planned by use of Pegger Software (Rogers, 2005). We were trying to design new variants in places which had more appropriate condition for road constructing. Accordingly, after planning these two variants, there are two variants named Traditional Planning Variant (TP_Variant) and Pegger Planning Variant (PP_Variant) for comparing with Existing network (E_Variant).

**E. Evaluation of different road variants, choosing the most appropriate forest road network and compare with existing road network**

In this step of research, two new variants and the existing one are overlapped with potential map for forest road planning and then percentage of each variant which are passed through five different classes was measured. These five potential classes are named; very good, good, medium, bad and worse. These names are based on their priority for road designation. Therefore, in a potential map for forest road constructing the one which has the most suitable situation to road designation is named "very good" area and the one which has very bad situation to road designation is named "worse" area. Then, the percentage of each road variant located in the mentioned area was measured and compared with others. Road density and overlay percent (OP %) were measured for each road and inefficient area (figure 1) or dead zone (Pentek et al, 2005).

Road density was obtained using (1) formula and road spacing was determined theoretically using (2) formula as follows (Backmond, 1968):

RD=road length (m)/district area (ha) (1)

S× RD=10000 (2)

in which RD is Road Density and RS is Road Spacing. The cross which should cover both side of roads was determined to make a different buffer for each road based on its road spacing as follows:

Buffering width=RS/2

If road spacing is 1000 meters for example, the road has 500 meters buffering area on each side. Overlap area which is a criterion factor for analyzing the efficiency of road was determined for each road too.

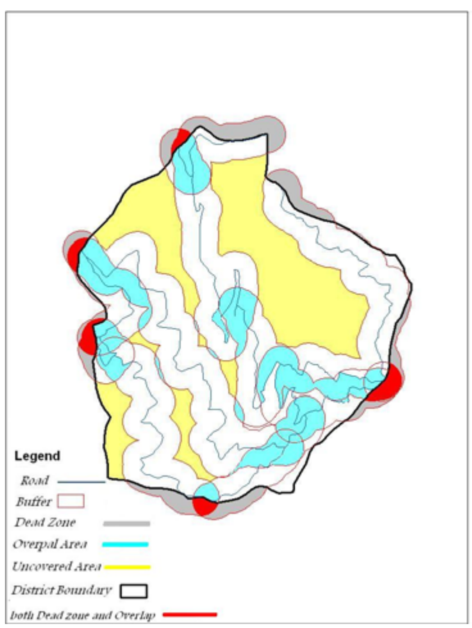



**Fig 1.** Overlaps, dead zones and uncovered area for existing road.

## RESULTS

### Analysis of different layers by using AHP

Analysis of different forest road layers construction based on expert judgments by the use of AHP showing slope with 0.216 and elevation with 0.030 coefficients have the maximum the minimum ranks, respectively.

Eight studied layers can be divided into two major classes indeed, A) the most important layers (value more than 0.125) and the least important layers (value less than 0.125), thus the most important layers include slope, hydrographic network, geology and soil layers and the least ones include volume ($m^3$ per hectare), tree type, aspect and elevation (fig 2).

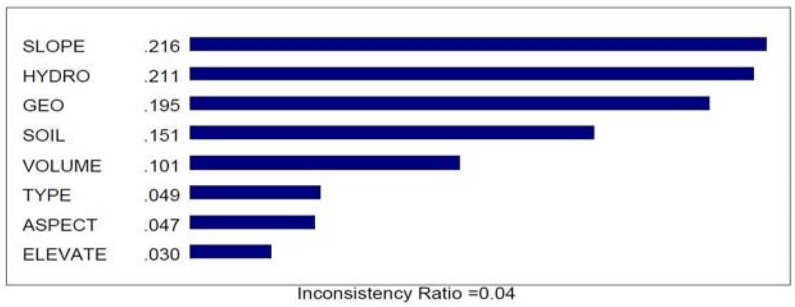



**Fig 2.** The results of data analyzed in Expert Choice software.

Potential map for forest road planning was created by overlaying all layers with different coefficients which is shown in figure 3. As it is shown, the study area from forest road construction point of view was classified into five classes namely very good, good, medium, bad, and worse.

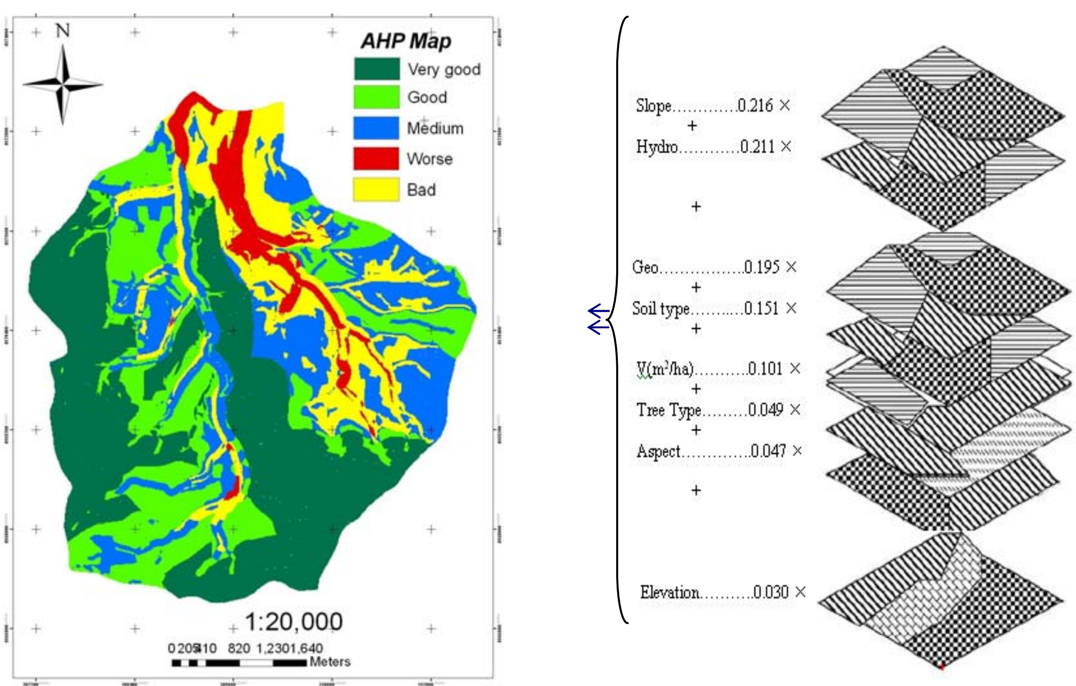



**Fig 3.** Prepared AHP map on Arc GIS software

**Analysis of variants from the point of view locating in each class**

Two different variants were designed by using Pegger software and the traditionally planner method (compass step). Regarding AHP map which had defined better area to road planning, we tried to design roads in a better situation (good and very good classes) more than other bad condition. As it is shown in figure 4, 5 and 6, the two new variants and existing roads have passed in different classes.

E_variant, TP_variant and PP_variant were passed 13.5%, 13.9% and 12.9% in bad and worse classes respectively, and they passed 64.4%, 74.8% and 79.3% in good and very good classes respectively in which PP_variant has a better performance in both situations stated above. E_variant, TP_variant and PP_variant were passed 22.1%, 11.3% and 7.8% in medium class respectively (fig 7)

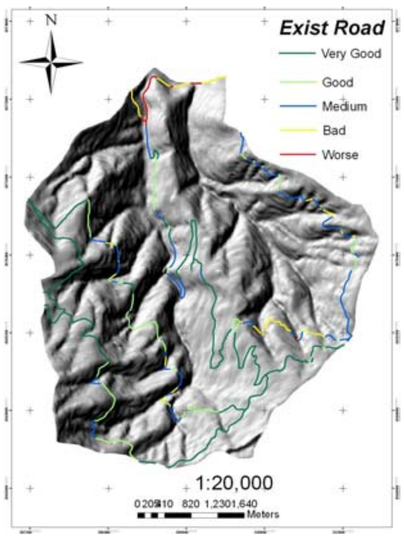



**Fig 4.** Distribution the ET_variant in the AHP classes

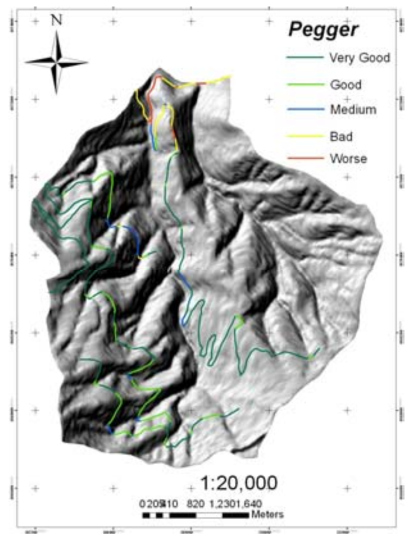



**Fig 5.** Distribution the PP_variant in the AHP classes

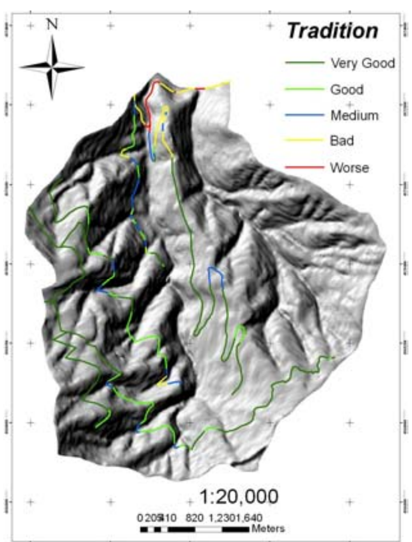
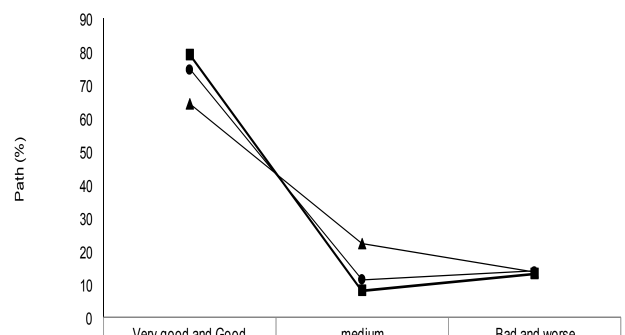



**Fig 6.** Distribution the TP_variant in the AHP classes




| | Very good and Good | medium | Bad and worse |
|---|---|---|---|
| T_Variant | 74.8 | 11.3 | 13.9 |
| P_Variant | 79.3 | 7.8 | 12.9 |
| E_Variant | 64.4 | 22.1 | 13.5 |

**Fig 7.** Percent of passing the variants in AHP map Classification

**Evaluation of road efficiency and effective performance**

Road density was 17.8, 15.3 and 14.2 m per hectare for E_variant, TP_variant and PP_variant respectively. Thus, based on 1A and 2A formula (Backmond formula, 1968), road spacing was 560, 650 and 703 respectively.

E_Variants is showen below as an example:

E_Variant: 1A) RD=40085m/2252ha = 17.8 m/ha. 2A) RS× 17.8 =10000⇨RS=561

Buffering width on each Side of Road=RS/2⇨ Buffering width=561/2=280.5⇨ BW=280

Therefore, buffers which were used for each variant were 280, 325 and 351 respectively.

After buffering, some overlap areas and dead zones were created where PP_varians has the most overlapping area and E_variant has the lowest overlapping area. E_variant has the maximum dead zone and TP_variant has the minimum dead zone (table 6).

**Table 6.** Road efficiency in each of the three variants

| | All road coverage | | Dead zone area (%) | Overlaps area (%) |
|---|---|---|---|---|
| | ha | OP% | | |
| E_ Variant | 1740 | 77.3 | 11.6 | 31.6 |
| PP_Variant | 1548 | 68.8 | 10 | 38.1 |
| TP_Variant | 1625 | 72.2 | 9.4 | 34.4 |

**Discussion**

Forest managers have to be concerned about road designing and construction more than past because of environmental impacts of forest roads and their cost (Lugo and Gucinshis, 2000; Dutton etal, 2005). North-east and east of study area areas with high slope and sensitive hydrographic networks and geological situations are not an appropriate location to design forest roads (Forestry planning cahier, 2009). Accordingly, we have decided to not design any road on the north-east and east of the study area because these areas have low value for road construction based on the potential map for forest road planning and also as recommended by forestry planning cahier.

In the current study, the most important layers were slope, hydrographic network, geology and soil. Naghdi and Babapour (2009) stated that the most important layers for road construction map are slope and stability layers. They prepared stability layers using soil texture and bed rock. Their results are similar to those of the current study. Their results indicated that slope, soil texture, bed rock and hydrographic layers are more important than other layers in expert's mind. This is because of their special effects on road planning and construction.

Field studies, inspections, and their being compared to the potential map for forest road planning (prepared AHP map) in this study have shown that AHP method regarding its specific properties can be a suitable and efficient method in forest road locating (Naghdi and Babapour, 2009; Raafatnia et al, 2006; Ezati et al, 2009). Flexibility, simplicity in computing and option ranking feasibility are some advantages of AHP method (Zebardast, 2002) that can be an effective help to evaluate diverse situations and road locating in the forest. In the review of different variants and their distribution in the five prepared sections in potential maps for forest road planning, PP_variant has the minimum path in the bad section (both bad and worse zones), thus it has a better performance than other variants (Rogers, 2005; Erikson, 2005). PP_Variant has a better performance in good situation for road constructing (good and very good zones) with maximum paths in them. But E_variant has the maximum paths in the medium zone. With an overall look at potential map for forest road planning and data, it can be concluded that PP_variant in the both bad and good situation has a better performance than other variants and can be introduced as the best option (figure7). By review of all points distributed in the variants, significant differences are just in bad and medium zones, but if all distributed points are compared in all variants in all five zones in the AHP map, it is seen that PP_Variant is better than other variants.

Using GIS to design and evaluate forest road variant is very effective (Naghdi and Babapoour, 2009; Majnounian et al, 2007) and not only does it lead to the simplicity of using AHP method (Raafatnia et al, 2006), but it can also be a good help in computing and analyzing data. It is proposed to be a good method in forest road network designing.

Ezzati et al (2009) used AHP and GIS in the ArcGIS software for forest landing locating. They reported that this method can be a good way to locate the landing in the forest. Using AHP and GIS together and also using Pegger as an appropriate method to design mountain forest road can replace the traditional methods in Iran (Naghdi and Babapoour, 2009; Raafatnia et al, 2006, Look, 2005)

Investigation of variants revealed remarkable results regarding the efficiency level. Road density for PP_Variant, TP_Variant and E_Variant were 14.2, 15.3, 17.8 m per hectare respectively. While E_variant has also a road section in the east and north-east of study area; therefore, has higher road density. But it has more dead zones than other variants and has had worse performance than others. TP_ variant with 9.4% dead zones had the best performance as compared to other variants. PP_variant has the maximum overlap and E_variant has minimum overlap (31.6%); as a result, E_variant had the best performance in overlaps. Generally, comparing variants in road efficiency has shown that E_variant has a better performance and situation than other variants, and it can cover wider range of areas than others. This is owing to the road segment located in the east and north-east of study area. This segment is located in a bad situation in the study area based on AHP map; therefore, we did not design any road there, and this is not a good reason to say E_variant has a better performance.

## Conclusion

Using GIS and AHP together to locate forest road can be introduced and done as a good method (Raafatnia et al, 2006). Suitable and unsuitable locations were determined using AHP and forest road efficiency was determined using GIS. In the current research, PP_variant had a better performance in path from bad and good situation than the two other variants based on potential map for forest road planning. E_variant had almost the best performance in road efficiency which is because of the road segment that is located in the east and north-east of study area. Regarding potential map for forest road planning, a forest road network can be introduced as the best variant which has more pass ways in the good situation and fewer pass ways in the bad situation. It should have an acceptable efficiency too. Accordingly, it seems that PP_variant can be introduced as the best variant in the current study environmentally.

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# طراحی شبکه جاده جنگلی در مناطق کوهستانی با استفاده از GIS و فرآیند تجزیه تحلیل سلسله مراتبی[1] (AHP)

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**چکیده**

ساخت جاده‌های جنگلی پرهزینه‌ترین عملیات در طرح جنگلداری می‌باشد. طراحی و ساخت جاده‌های جنگلی در مناطق نامناسب، نه تنها باعث افزایش هزینه‌های ساخت و تعمیر و نگه‌داری جاده می‌گردد بلکه اثرات زیست محیطی فراوانی را نیز در پی دارد. بنابراین، طراحی جاده‌های جنگلی توجه بیشتری را می‌طلبد. در این تحقیق، سعی ما بر این می‌باشد که روش مناسبی را جهت مکان‌یابی جاده‌های جنگلی با استفاده از سیستم اطلاعات جغرافیایی (GIS) و فرآیند تحلیل سلسله مراتبی (AHP) معرفی نماییم. ابتدا مهمترین لایه‌ها در مکان‌یابی جاده‌های جنگلی شامل شیب، نوع خاک، زمین‌شناسی، آب‌نگاری یا هیدروگرافیک، جهت جغرافیایی، حجم در هکتار (مترمکعب)، تیپ درختی و ارتفاع از سطح دریا تعیین شد و سپس منطقه مورد مطالعه با توجه به نظر کارشناسان و متخصصان جاده سازی جنگل و با استفاده از فرآیند تحلیل سلسله مراتبی به پنج دسته بسیارخوب، خوب، متوسط، بد و بسیار بد جهت ساخت جاده طبقه بندی شد. سپس دو واریانت جدید بر روی نقشه تهیه شده طراحی شد؛ واریانت اول به روش معمول (گام پرگار) و واریانت دوم با استفاده از Pegger طراحی شد. در نهایت با مقایسه شبکه موجودی با دو واریانت جدید، واریانت دوم بهترین کارایی را در عبور از مناطق مناسب و نامناسب بر اساس نقشه پتانسیل جهت جاده‌سازی داشت. نتایج حاصل از این تحقیق نشان داد که استفاده از سیستم اطلاعات جغرافیایی و فرآیند تحلیل سلسله مراتبی به صورت توأم، می‌تواند به عنوان روشی کارا در طراحی جاده‌های جنگلی مورد استفاده قرار گیرد.

1. Analytic Hierarchical Process