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Forest Road Network Design based on Multipurpose Forestry Management in Hyrcanian Forest

ABSTRACT

Traditionally, the main focus of forestry management has been based on wood production but more recently it is directed at multifunctional forest management. Multifunctional forestry management includes many considerations such as ecotourism, ecology, economic and social issues of forest dwellers as well as wood production. This study aims to design forest roads using GIS and satellite data of SPOT-HRG in the Darabkla forest based on Multipurpose Forestry. The study used the multi-criteria evaluation method based on fuzzy logic to assess the potential of land area for a road network. Opinions of experts and scholars were used to select four criteria and 18 sub-criteria for road design. Analytical Hierarchy Process (AHP) was used for weighting factors. Layers were combined using a weighted linear combination (WLC) operator and the map of crossing the road potential was identified and zoned. The road was designed using the PEGGER program. Geographic Information System (GIS) and satellite data of SPOT-HRG were effective tools for improving outcomes. Weighted Linear Combination (WLC) Model for combination layers was used in this study and recommended the multi object operation (MOLA) in future studies.

Key words: *multipurpose forestry, road design, multi-criteria evaluation, AHP*

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INTRODUCTION

Forests have plenty ecosystem services that aims to provide protection against soil degradation and forest activities such as wood production. Hence, application of multifunctional forest management is increasingly replacing the prevailing practice which is based on wood production. The goals of such a management system include considerations of ecotourism, ecology, economic and social issues of forest dwellers in addition to wood production (*Amani 2000*). Improving the prevailing practice based on wood production to a more multidimensional view of forest productivity that includes ecotourism, which as an industry with high efficiency, could maximize the potential of forest management in terms of placing value on the preservation of landscape and ecological issues in road design. Roads are essential within forest areas for access and transportation of forest products and services. It is necessary to consider preservation of the natural beauty of the area as well as its ecosystem, biodiversity and sites of species at risk, designated areas for fishing and hunting, other local recreation areas and economic and social needs of inhabitants of the forest. If forest roads were designed with consideration of all these mentioned factors, it would attract tourists, whichcan provide a good economic resource for the country. The study of *Coulter et al.* (*2006*) reported that western states of USA used the AHP method to determine the priority of road maintenance and to determine benefits such as repair or improvement of the roads. *Keshkmat* (*2007*) studied the evaluation and formulation of transportation options using multi-criteria evaluation and network analysis in Poland. Results showed that effective decisions for designing a transportation network could be made using network analysis and multi-criteria evaluation. Most studies in Iran have only used GIS. In addition, layers have been overlapped to derive a map of potential passages (*Hosseini 2004; Abdi 2005; Mustafa 2007; Hayati et al. 2012, 2013; Babapour et al. 2014, Gülci, and Akay,2015; Zandebasiri and Pourhashemi 2016; Nilson et al. 2016*). *Abdi et al.* (*2009*) performed a study using GIS and multi-criteria evaluation to reduce the cost of road construction. Results showed that the use of GIS and multi-criteria evaluation would improve the design steps. *Akay et al.* (*2018*) studied to comprehensively assess the risk factors in forest road design and construction using the fuzzy analytic hierarchy process (AHP) method in Turkey, thus contributing to the proper performance of these activities *Mahini etal.* (*2008*) evaluated nature-sightseeing in Behshahr using multi-criteria evaluation based on fuzzy logic.

Determinations of factor weighting were made by Analytical Hierarchy Process (AHP) and weighted by a weighted linear combination operator. All layers were combined and a raster map of nature-sightseeing potential was prepared. This study used GIS, the sensor data of SPOT-HRG and operator of a weighted linear combination (WLC). This method is compared with traditional ones and those based on Boolean logic, with an uncertain fuzzy logic for real world modeling in GIS and spatial data integration for greater accuracy. This study aims to determine the best route for the proposed road using a method of multi-criteria evaluation (MCE) named weighted linear combination (WLC) and using GIS and SPOT-HRG satellite data.

Materials and Methods

Study area

The study was carried out in 2013 at Darabkla forest, which includes two series (series 1 and 2) and it is located in the city of Sari (**Figure 1**). Based on coordinate system UTM in this region is located on Zone 39 and its coordinates in this system of latitude and longitude based on WGS84 are: 53˚ 27' 09" to 53˚ 34' 19" E and 36˚ 46' 74" to 36˚ 55' 57" N. The area is located between 180 and 880 meters above sea level and the average annual precipitation is 938.8 mm. The study area has a cold and humid climate based on Amberzhe method (*Kalbi et al. 2014*).

In this study, numerous data and maps have been used and these are given in Table 1. Initially, data was assimilated according to the scale of the system of geographic coordinates. Data was prepared in a raster format with a cell size of 10 m.

Methods

The research method was carried out using the required data, maps and information in several steps (**Table 1**):

Factors affecting road routing. Using field visits, expert opinions and the needs of multifunctional forestry management were identified and mapped on a GIS environment. Factors involved in the road routing process included ecological, geomorphologic, socio-

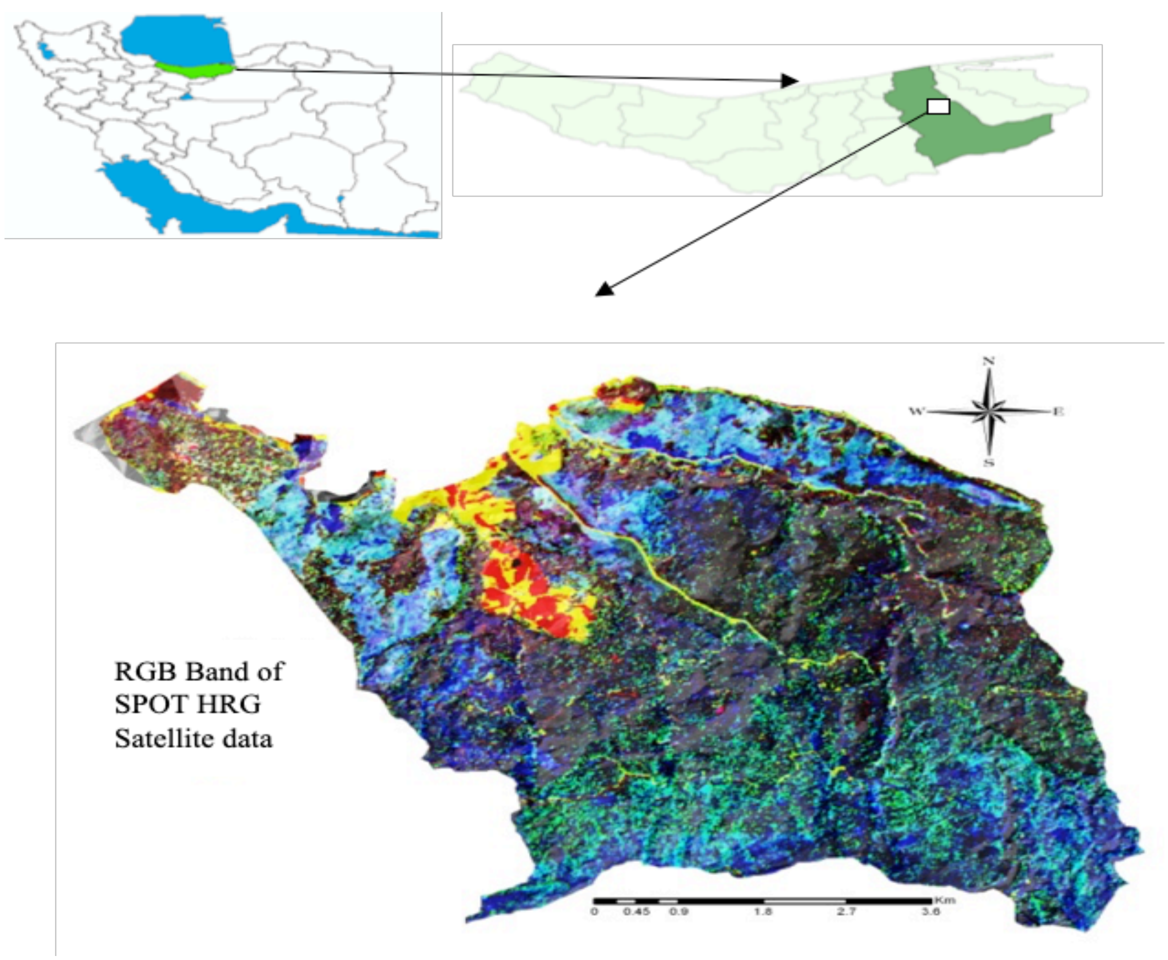

Figure 1. Location of the study area in Iran (a), Mazandaran province (b) and the study area (c).

Table 1. Data and Maps of Study.

Row	Maps	Row	Maps
1	Soil map scale of 1:25000	10	topographic maps scale of 1:25000
2	Map of stand forest volume scale of 1:25000	11	Map of forest type prepared using satellite images of SPOT-HRG
3	Map of non-wood forest products using field practices		
4	Plantation map prepared from type map	12	Map of agricultural land using field practices
5	Map of the rare species using field practices	13	Digital elevation model with a resolution of 10 m
6	Slope and aspect map prepared from DEM	14	Geological map scale of 1:25000
7	Map of Landslide prepared using field practices	15	Image sensor SPOT- HRG
8	The village map derived from satellite image	16	Facilities and perspective maps prepared using field practices
9	Map of distance from water using field practices		
		17	Map of existent road derived from topographic maps
		18	water flow network map derived from topographic maps scale of 1:25000

economic and ecotourism: ecological factors; plantation, existence of rare species; geomorphologic factors; slope, aspect, elevation, geology, landslides, soil, hydrographic; socio-economic factors; presence of agricultural land, villages, existing roads, utilities, non-wood forest products, forest stand volume; and ecotourism factors; landscape, water resources and type of forest stand.

Standardized factor maps and criteria. Since there were varieties of values involved in measuring criteria, it was necessary that each of these criteria be standardized before combination. In this research, standardization of the factor map was performed according to fuzzy logic on a byte scale (zero to 255) and the definition of membership functions. It was necessary to determine threshold criteria and type of function membership in order to make fuzzy factor maps. Here, threshold criteria were identified using expert opinions and a review of the related literature. The following types of function membership were used in this study; discrete functions, monotonically increasing and monotonically decreasing linear forms.

Weighting factor using AHP. Analytical Hierarchy Process (AHP) is one of the most famous technique in multi-criteria decision making which was first developed by *Saaty* (*1980*) (*Ketabi et al. 2005*). It is a popular method for factor weighting used in many fields such as natural resource management (*Kangas 1992, Nordstrom 2010*). It also has the highest efficiency in forest management and the range of its application continues to increase (*Reynolds 2001*). The AHP method has many benefits such as its multipurpose application and cooperation planning. Combining and analyzing AHP detailed information, specialist knowledge and preference topics, qualitative criteria can be evaluated in the same way as quantitative processes (*Saaty 1977*). In this phase, experts in the field of forestry were involved as the study population. The required criteria are at least five years' job experience and having a Ph.D. degree. Overall, 18 experts participated in the present study.

Multi-criteria evaluation through Weighted linear combination (WLC). It is the most common technique for analysis and multi-criteria decision-making. This technique is simple, with an accumulate weighting and scoring. The purpose of multi-criteria analysis is to select the best alternative (i.e., identification of the best places or pixels), evaluations are based on rating through multi-criteria evaluation. There are several methods for multi-criteria evaluation, the most important of which are weighted linear combination, the ideal point and agreement method (*Malczewski 1999, Vainkainen et al. 2008, Kangas et al. 2008*). In addition to choosing a scale for preparing fuzzy maps, the fuzzy function should be studied and selection made for the most appropriate function for the criteria. Some famous functions are Sigmodial, Linear and J-shape. Selections are made at points in increasing or decreasing trends. Here, decreasing means minimum or descending function and increasing means maximum or ascendant function.

Weighting method. After the evaluation, criteria were converted to standards and comparable scales, weight and relative importance was determined according to purpose. In this study, the AHP of *Saaty* (*1980*) was used to determine the relative weight of each criterion. Pair wise comparison in Idrisi software was used as a method for determining criteria weights for multi-criteria decision-making in GIS. Weight for each criterion was calculated from questionnaires and experts' opinions and weight was calculated for each criterion from the order of weights. But the AHP used pair wise comparison. Firstly, each studied criterion was compared and relative importance for each pair was given a score from the scale of 1 to 9 and entered in a matrix. Then, weights and proportions of agreement (CR) were calculated, if this ratio was less than 0.1, the comparison was accepted and calculated weights were determined. If a ratio was greater than 0.1, then pair wise comparison would be set to an acceptable level by changing the matrix. This can be done through computing the consistency ratio (CR) from the consistency index (CI) and the random index (RI), as follow:

CR= CI/RI

$$CI = \frac{\lambda_{max-n}}{n-1}$$

Preparing a map of the road passage. The next step is standardization of criteria maps combining the different layers of information by WLC. Then, according to the equation (1-1), each of the factors were multiplied to its weight and an appropriate road passage map was achieved from sums of the results.

$$S = \sum wixi \quad (1)$$

Where S: desirable, Wi: weight of factor i, Xi: fuzzy value of i

Designing a proposed path using PEGGER. GIS was used in ArcView software environment for designing roads. PEGGER program is an extension of the software that automatically predicts a road's passage. The main feature of this program is the possibility of the practical use by individuals. The work is based on lines of the base curve that can be introduced to software in different formats.

Evaluation of the designed path. PEGGER software was designed solely to identify paths in relation to arbitrary slopes and it lacks an ability to evaluate the economic and environmental constraints that should be considered by the designer. Such analysis can be implemented in GIS, but it cannot be applied in PEGGER software. After designing, the proposed variants were studied and analyzed by the cover percentage method. In this method, after determining the skidding boundary, it was then drawn around the proposed road and then covered and uncovered or inaccessible areas and overlapped areas were assessed.

RESULTS AND DISCUSSION

After preparing the map of affective factors on road routing, standardization of maps was prepared according to fuzzy logic in a byte scale (zero to 255) and definition of membership function that in this range, higher values had higher desirability and smaller values had less desirability. In order to make fuzzy factor maps, it is first necessary to determine the criteria threshold values and shape and type of membership function (**Table 2**). Here, criterion threshold values were identified using expert opinions and from a review of related literature.

The results derived from weighting using AHP showed that the factor of distance from village, with the weight of 0.12 and the factor of stand type with the weight of 0.0053 had the highest and least values, respectively (**Table 3** and **Figure 2**).

Table 2. Factor maps criteria, threshold shape and type of membership function.

Row	Factors	shape and type of membership function
1	Slope	Decreasing uniform linear
2	Aspect	Discrete
3	Altitude	Discrete
4	Distance from streams	Decreasing uniform linear
5	Distance from agricultural Land	Decreasing uniform linear
6	Distance from village	Decreasing uniform linear
7	Distance from facility	Decreasing uniform linear
8	Distance from water resources	Decreasing uniform linear
9	Standing Volume inventory	Increasing uniform linear
10	Distance form landscape	Increasing uniform linear
11	Type of stand	Discrete
12	Soil	Discrete
13	Geology	Discrete
14	Distance from sliding points	Increasing uniform linear
15	Distance from non-wood forest products	Decreasing uniform linear
16	Distance from the plantation	Decreasing uniform linear
17	Distance from rare species	Increasing uniform linear
18	Distance from the road	Decreasing uniform linear

Table 3. Weights obtained by the AHP method.

Row	Factors	Weight	Row	Factors	Weight
1	Slope	0.069	10	Distance form landscape	0.03
2	aspect	0.006	11	Type of stand	0.005
3	Altitude	0.008	12	Soil	0.05
4	Distance from streams	0.01	13	Geology	0.05
5	Distance from agricultural Land	0.078	14	Distance from sliding points	0.09
6	Distance from village	0.12	15	Distance from non-wood forest products	0.05
7	Distance from facility	0.109	16	Distance from the plantation	0.04
8	Distance from water resources	0.01	17	Distance from rare species	0.08
9	Standing Volume inventory	0.085	18	Distance from the road	0.09

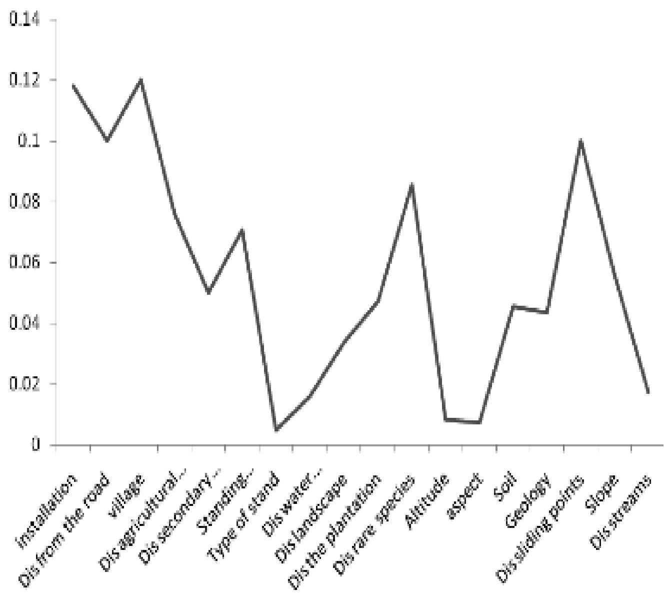

Figure 2. Weights and factors from by the AHP method.

According to results derived from the passage capability map based on AHP weighting, the area (1,519 ha) was divided into five parts considering passage capability. Nine hectares with an average passage capability covering 31.8% of the total land area had the highest land area allocation, while an area of 259.9 ha with very good passage capability covered 5.4% had the lowest (**Figure 3** and **Table 4**).

Table 4. Areas and relative areas of the passage capability map based on AHP.

Area Rank	Road Passage Capability in Area	Area (ha)	The Total Area of the Region (%)
1	bad	277.1	5.8
2	weak	1243.1	26.11
3	Average	1519.9	31.8
4	Good	1485.5	30.9
5	Very good	259.9	5.4

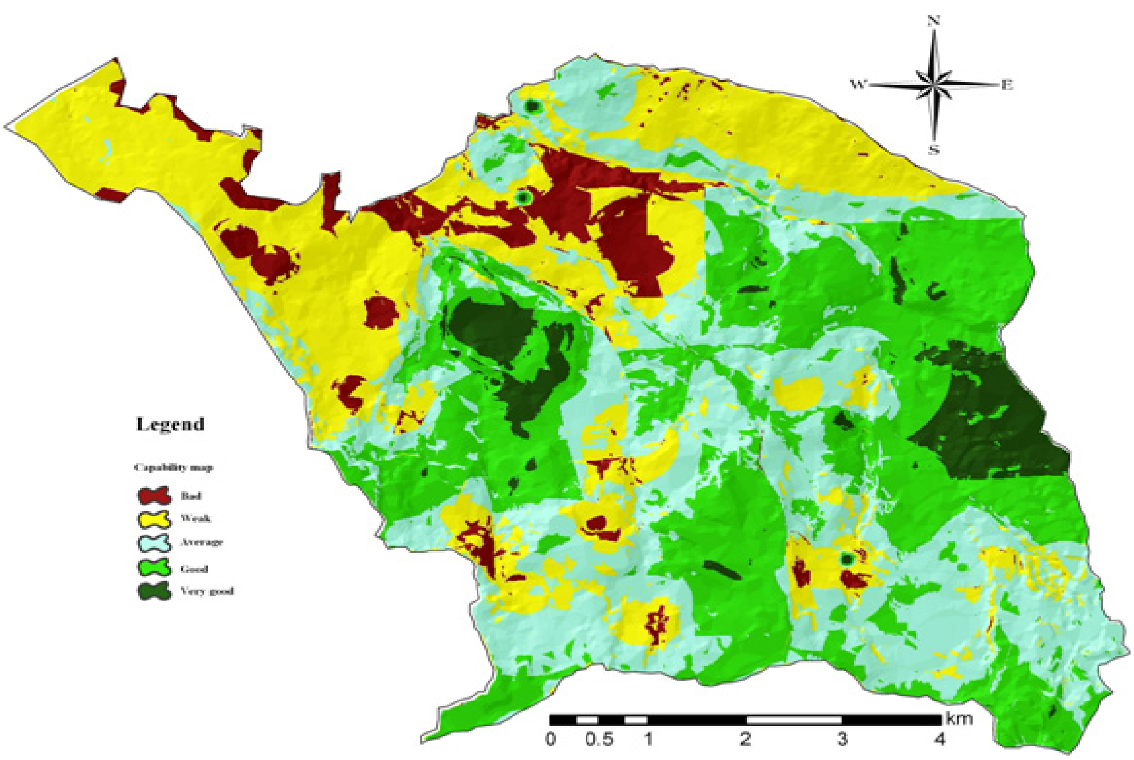

Figure 3. Location of the study area in Iran (a), Mazandaran province (b) and the study area (c).

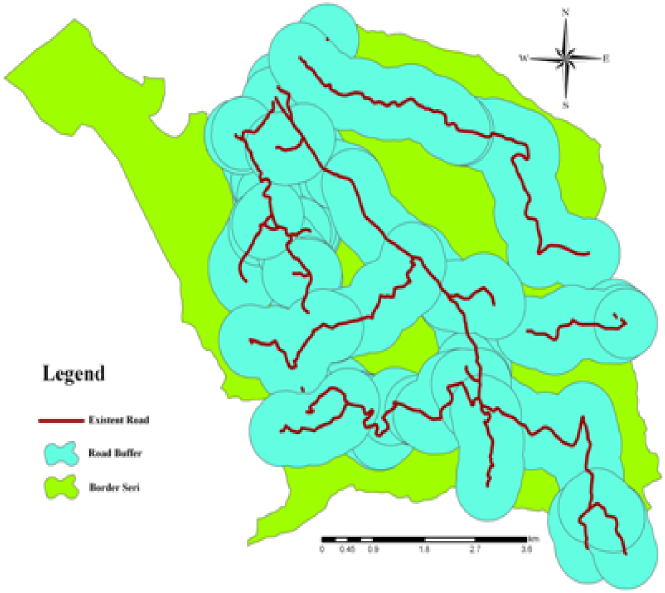

Figure 4. Existent road and surface area covered.

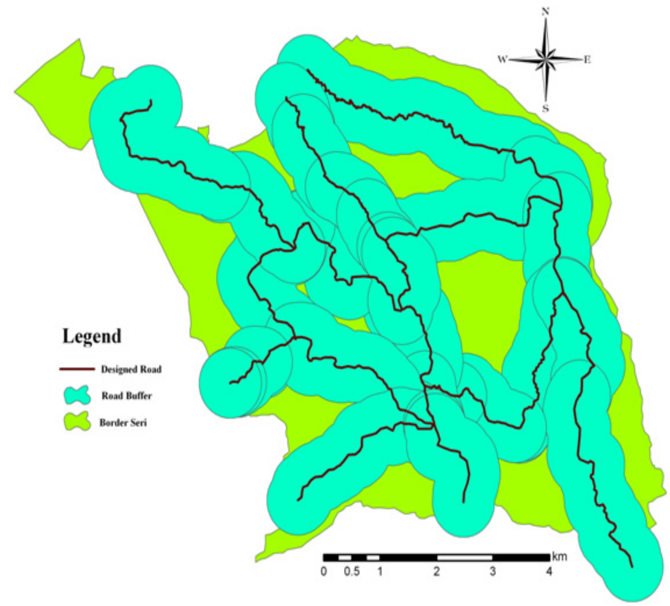

Figure 5. Designed road and surface area covered.

Table 5. Existent and designed roads using the cover percentage method.

Road	Total Length (m)	Series Area (ha)	Density (m ha^{-1})	Road Distance (m)	Transport Distance (m)	Average Transport Distance (m)	Cover Percentage
existent	43,200	4,785.5	9.02	1,108.6	554.3	277.15	58.3
designed	52,140	4,785.5	10.8	925.9	462.95	231.4	61.2

The existent and designed roads using the cover percentage method determined covering values of 58.3% and 61.2%, respectively (**Figures 4, 5** and **Table 5**).

CONCLUSIONS AND RECOMMENDATIONS

Scientific management of the Darabkola forest had applied the shelter wood method since 1966. As such, existing roads in the area appear to have been designed according to a one-dimensional view associated with the shelter wood method. In the past, only factors such as hydrology and slope were considered in road design. But current road design requires consideration of additional factors such as conservation of biodiversity, sites of species at risk, designated areas for fishing and hunting, other local recreation areas and economic and social needs (*Sarikhani 1999*). Thus, the aim of this study was todesign roads based on multi-purpose forestry using GIS and remote sensing data. To determine the effects of each of the 18 factors examined in this study on road design the necessary investigations were carried out by experts to determine the effect of each factor in producing a map of road passages (**Table 1**). In this study, the highest weight was dedicated to socio-economic related criteria (**Table 3**). The results were in agreement with those of *Majnoonian et al.* (*2010*), which indicated that the socio-economic factor is one of the major factors in road design. Layers of slopes and landslides were the most important geomorphologic factors and this result was in agreement with results of other research (*Hosseini 2004; Abdi 2005; Mostafa 2007; Soleymanpour 2010)*. Decision-making is a fundamental element of place, and space is considered as a geographical factor. The method of weighted linear combination is the most common technique used for analysis and evaluation of multi-criteria decision making. This method is based on averages of weights. Analyst or decision makers directly based on "relative importance" of each criterion, gives a weight to each criterion then a final value for each option is obtained by multiplying the relative weight to the value of a factor. After determining the final value of each option, the option with the highest value would be the most suitable for the intended purpose. Results showed that combining this technique with GIS would increase the ability of this method and that it was effective in improving the outcome. These results were in accordance with those of *Mahini et al.* (*2008*). The designed road had an acceptable covering which was 60-70% (**Table 4**). This rate was acceptable (*Lotfalian and Parsakhoo 2012*). Using GIS capabilities, primary roads were easily determined for wide areas such as those in the present study and in less time than using hand or compass methods. To use the PEGGER program in GIS, taking advantage of the contour map and based on the longitudinal slope in designing a road between two points, different options for roads can be offered. In addition, there is no need to introduce new variants in this method and the most appropriate road could be selected by quickly offering different roads and analysis in a GIS environment (*Abdi 2005*). In this study we used Weighted Linear Combination (WLC) Model for combination layers, recommended in later study used multi object operation (MOLA).

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