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A MULTIVARIATE METHODOLOGY FOR DETERMINING THE OPTIMAL HIGHWAY ALIGNMENT CANDIDATE BASED ON GEOGRAPHIC INFORMATION SYSTEM AND ANALYTIC HIERARCHY PROCESS

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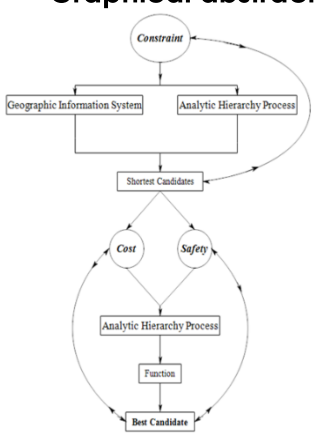
Graphical abstract



Abstract

Research on highway alignment optimization has been quite intensive over the last two decades. Determining the best candidate for highway alignment is one of the most complex highway design stages due to the different effects of various parameters. Hence, in the present study, Analytic Hierarchy Process technique and Geographic Information System are proposed to determine the best highway candidate with special focus on the constraint, cost and safety criteria. The methodology presented in the current research is not limited to the constraint, cost and safety criteria but can be extended to other criteria. This methodology has been implemented on a case study region in northwestern of Iran, and therefore the constraint, cost and safety criteria have been obtained for the case study conditions. The final result of the current paper indicates that the optimal highway candidate obtained with the proposed methodology can concurrently satisfy all relative parameters in highway alignment optimization based on their impact.

Keywords: Constraint, cost, safety, optimal highway candidate, AHP, GIS

1.0 INTRODUCTION

A great deal of research effort has been made in recent years to develop methods of determining optimal highway candidates. So far, several extensive research works have been carried out to determine optimal alignment worldwide, which has led to the emergence of different models and algorithms. Some of the most important are: calculus of variations [1], network optimization [2], dynamic programming [3], genetic algorithm [4], and geographic information system [5]. For instance, in the genetic algorithm method proposed by Jong [4], the optimal candidate is obtained by investigating only the sensitive and dominating costs. All models that are presented for highway alignment optimization perform alignment optimization only by minimizing the total cost. Meanwhile, determining the best highway candidate is very complex and several parameters play a role besides cost, such as safety, constraint, and so on.

Constraints parameters are effective in determining optimal alignment of highways and divided into two main categories, namely design constraint (e.g., allowed gradient, minimum radios, sight distance, etc.) and environmental and geographical constraint (e.g., crossing landslide areas, crossing faults areas, crossing snowy areas, historical site, etc.). Lack of attention to constraints in determining the optimal highway alignment will be led to adverse environmental or engineering effects.

Costs also are one of the important parameters in determining the optimal highway candidate. The cost parameters in highway alignment optimization are divided into direct and indirect costs. Indirect costs are paid by government and private sector investments (e.g., costs related to highway design, construction, maintenance, air and noise pollution, etc.), while direct costs are paid by highway users after highway operation (e.g., vehicle operating costs, lost time costs, toll and parking costs, etc.). The four categories of cost functions considered in this study include length-dependent cost, structural cost, location-dependent cost and earthwork cost. The results of each cost category for a highway candidate can express the weight of that candidate as well as the weight of every cost category.

Another significant parameter that plays an important role in highway alignment optimization is safety. Global statistics indicate that over one million people lose their lives in road accidents annually. According to the latest report by the World Health Organization (WHO), road injuries that lead to death are among the top 10 causes of death all over the world. The statistics provided by WHO indicates that around 1.3 million people died in road accidents in 2012 worldwide. A similar statistic shows that nearly 25000 people lose their lives in Iran annually in road accidents. According to studies conducted in Iran, the main causes of accidents are, respectively: human factors (70%), road and environmental factors (20%), and vehicle factors (10%). According to statistics, the effect of road and environmental factors is substantial in road accident occurrences in Iran. With correct routing and use of all effective parameters in determining the best highway candidates, such as compulsory points, seas, marshes, rivers, hydrology, geology, faults, landslides, etc., the rate of accidents can be reduced.

The current paper presents a new methodology for determining the best highway candidate using the Analytic Hierarchy Process technique and Geographic Information System with specific focus on the constraint, cost and safety parameters. The weight of each constraint and safety parameter relative to the others is obtained through questionnaires. However, the weight of each highway candidate based on every safety and cost parameter is obtained by extracting the safety and cost parameters from the highway candidates and then using a method defined in this paper. Finally, the weights obtained for constraint, cost and safety will be used in the AHP technique, after which the best highway candidate will be attained based on the provided methodology. The best candidate found according to the proposed methodology can satisfy all parameters used simultaneously. In this research an example is provided for showing how working proposed methodology to highway alignment optimization. This example is a path between Qeydar-ZarrinRood cities in north western of Iran (Figure 1).

Figure 1 The case study region for the current research

The constraint, cost and safety parameters investigated in the current paper are based on conditions of this case study and can be changed and promoted for other territories.

2.0 PROPOSED METHODOLOGY

This research provides a new methodology for determining the best candidate of highway between origin and destination points. This methodology is based on integrating Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) with a focus on constraint, safety, and cost criteria. These three criteria cover all of the parameters that are important in determining the best candidate of highway alignment. A simple flowchart of this methodology is provided in Figure 2.

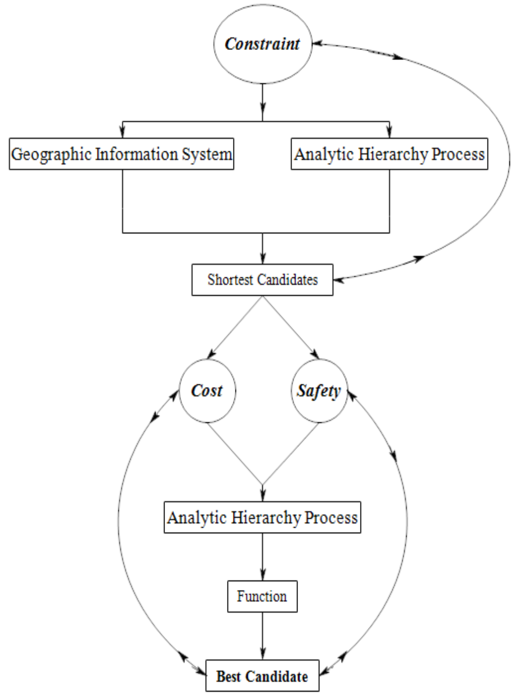


Figure 2 Simple flowchart of the final methodology based on GIS and AHP

According to flowchart provided in Figure 2, this methodology is divided into three following phase.

2.1 Phase 1

In this phase initially based on condition of each case study and project, several layers related to constraint parameters will be collected. Afterward, it is needed to have different candidates between origin and destination points with the different constraint, cost and safety values. Therefore, in this research, it is suggested that around an imaginary straight line between origin and destination point, several buffers with different size is supposed for each constraint layer. With a greater number of buffers and shorter buffer extents, the final result that indicates the best highway candidate will be more accurate. Then, each constraint layer in each special buffer will be classified based on the lower constraint, the lower class. For example, in slope layer based on different regulations of road design, the maximum allowable longitudinal slope has been limited to a special value (e.g., the maximum allowable longitudinal slope for highway in regulation of highway design in Iran is equal to 6%). Therefore, the lower class should be assigned to lower slope. Other constraint layers also follow of this method for classifications. Continue on this phase the classified constraint layers will be integrated based on algorithm raster calculator or AHP extension in ArcGIS software and finally the shortest candidate in each buffer will be created. Each candidate which is defined by this method has the best condition of constraint in a special buffer and different cost and safety value. This phase is shown in flowchart provided in Figure 3 completely.

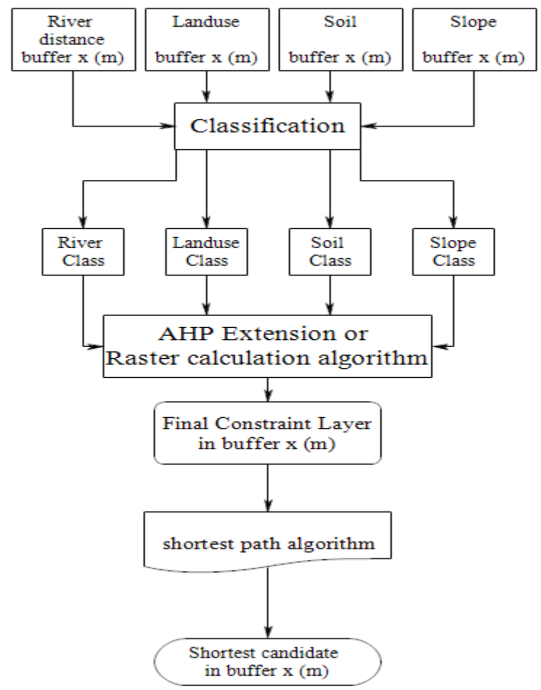


Figure 3 Comprehensive chart of phase 1 for x (meter) buffer size

2.2 Phase 2

In this phase, parameters of constraint, cost and safety related to each of the obtained candidates from phase 1 will be calculated. These parameters are based on cost equations and safety literature reviews. This process is shown in Figure 4.

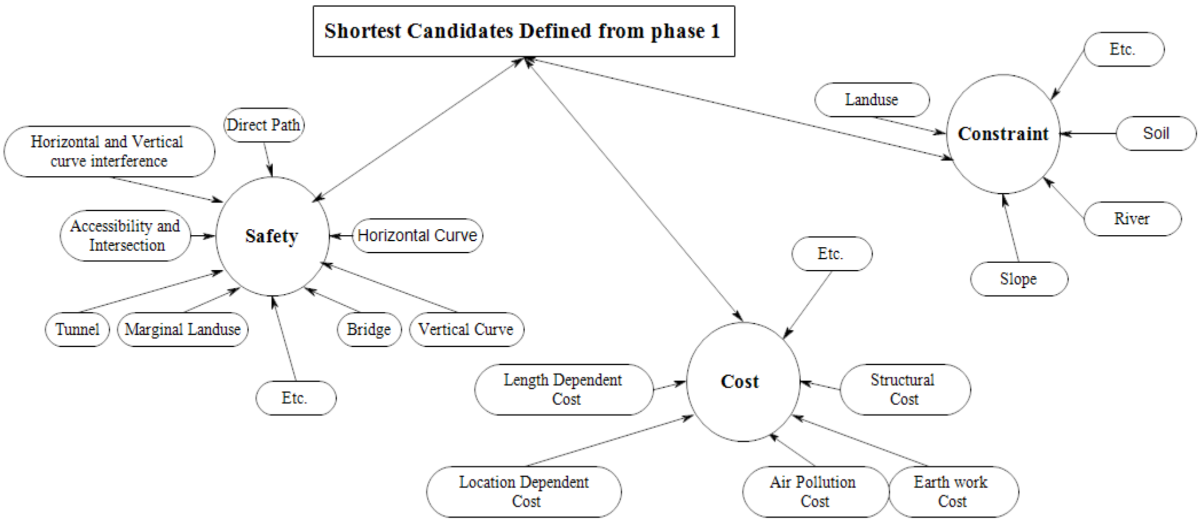


Figure 4 Calculation of parameters values related to constraint, safety and cost for each candidate

Afterward, the weight of each candidate based on each category of constraint, cost and safety as well as the weight of each category of constraint, cost and safety relative to each other will be calculated. These weights will be used in the next phase for determining the best highway candidate.

2.2 Phase 3

In this phase the best highway candidate among candidates defined in phase 1 will be determined by using Analytic Hierarchy Process technique. In the hierarchy, the goal is to determine the best candidate, and the criteria are constraint, cost and safety parameters of presented candidates, and alternative for this goal will be the defined candidates from phase 1 which shows the shortest candidates between origin and destination based on different buffers around the study area. This process is shown in Figure 5.

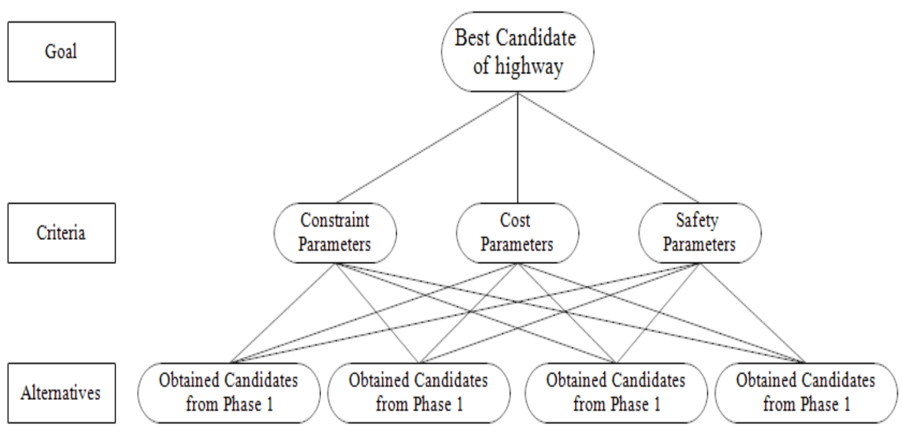


Figure 5 AHP hierarchy for proposed methodology

3.0 CONSTRAINT PARAMETERS

In current research, four constraint parameters have been used for proposed methodology namely soil, land use, slope and river based on case study condition. According to explanations provided in phase 1, each of these constraint layers initially are divided into several buffers (in current paper to three buffer size namely 1500 m, 2500 m, 4500 m) and then each layer has been classified (Figure 6). Then the classified layers in each buffer are integrated based on weights obtained from questionnaires which the final result of them are provided in Table 1. Finally the shortest path has been created for each buffer (Figure 7).

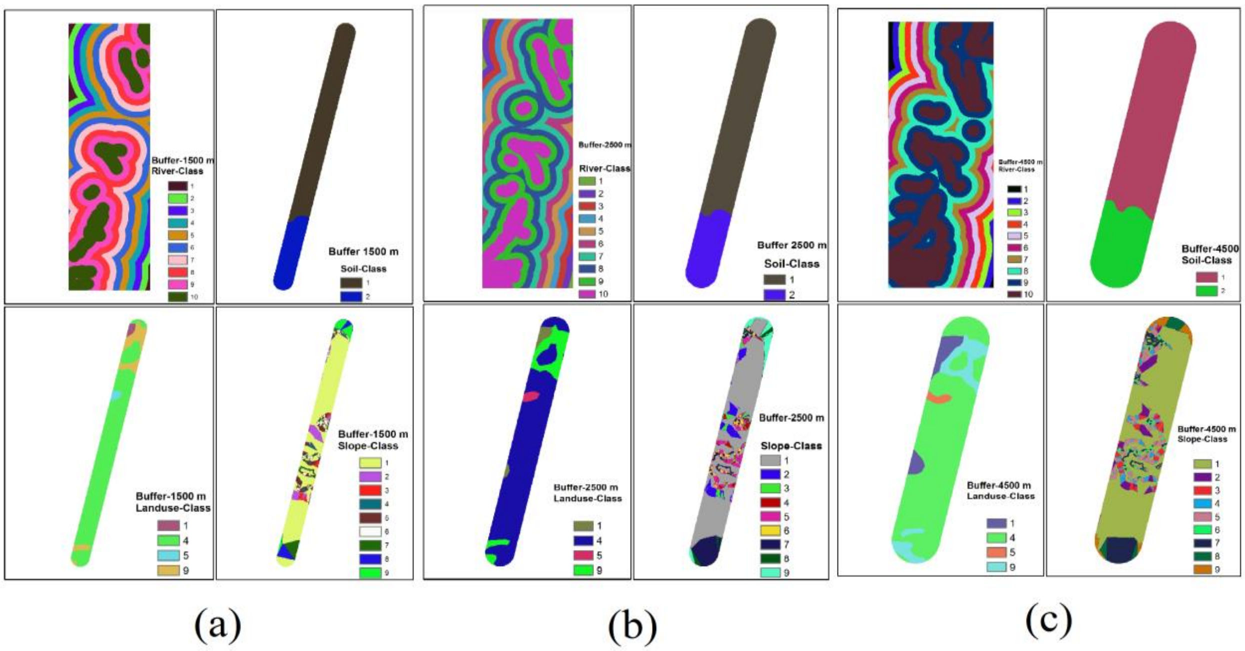


Figure 6 Constraint layers in different buffer size (a) 1500 m, (b) 2500 m and (c) 4500 m

Table 1 Questionnaire results that show the AHP weights of the constraint layers in the case study region

Layer Name	AHP Weight
SLOPE	0.52
LANDUSE	0.18
SOIL	0.18
RIVER	0.12

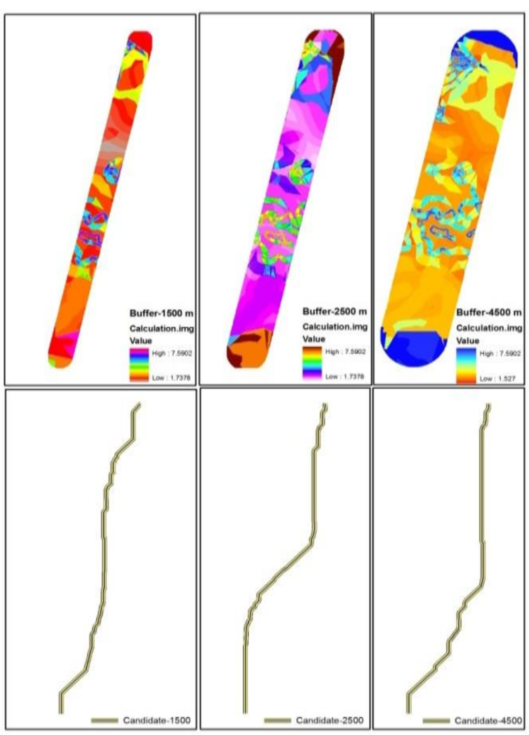


Figure 7 Final constraint layers and their candidates

3.1 Constraint Weight

In the previous section, four constraint layers were investigated based on the case study conditions. All of these constraint layers can be used in the current study in order to determine the weights of the constraint parameters for each highway candidate as well as each class of each layer.

In this study, a method for determining the constraint weights is suggested. To determine the AHP weight of each candidate based on each class of each constraint parameter, the length of each defined candidate by phase 1 in each class of each constraint layer should be initially calculated. Afterward, the AHP weight of each highway candidate based on each class will be obtained based on the flow charts provided in Figures 8-9. Output results from flowchart provided in Figure 9 will be used in Expert Choice software for determining the best highway candidate.

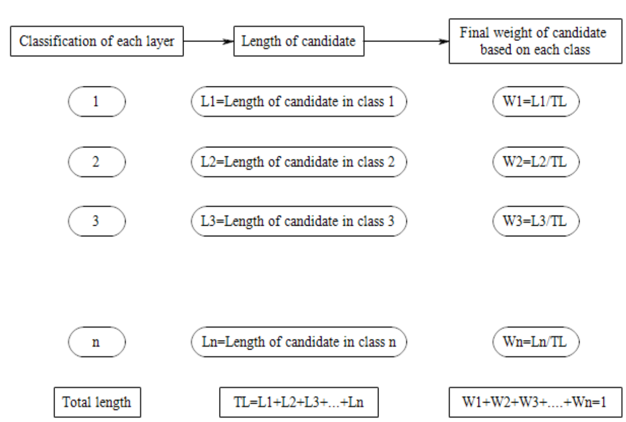


Figure 8 Final weight of each candidate based on each class

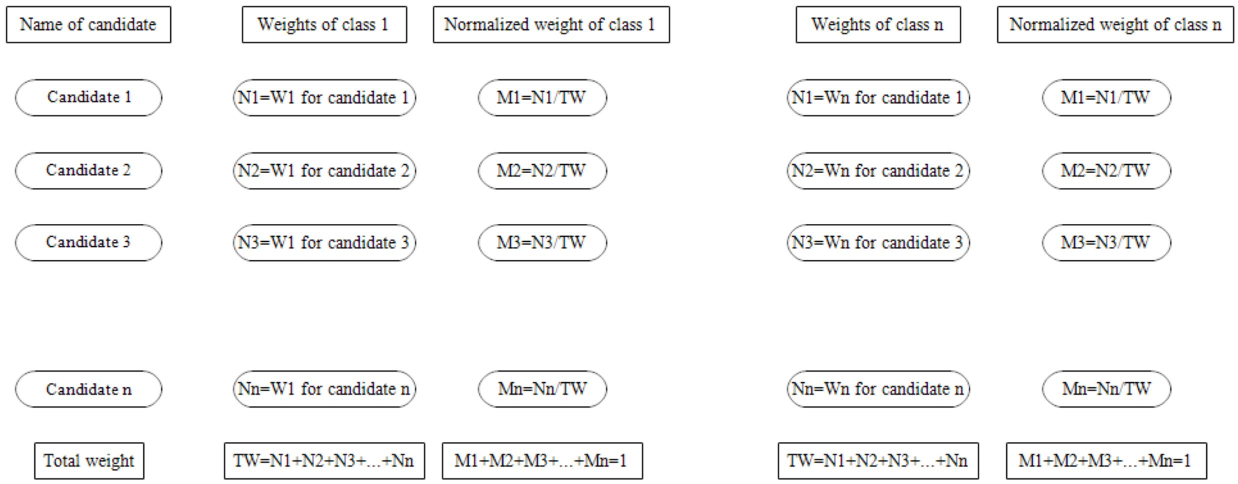


Figure 9 Final weight of each class among of all candidates

The weight of each class of each constraint parameter among all classes can be calculated by using flowchart provided in Figure 10 for proposed methodology in this research.

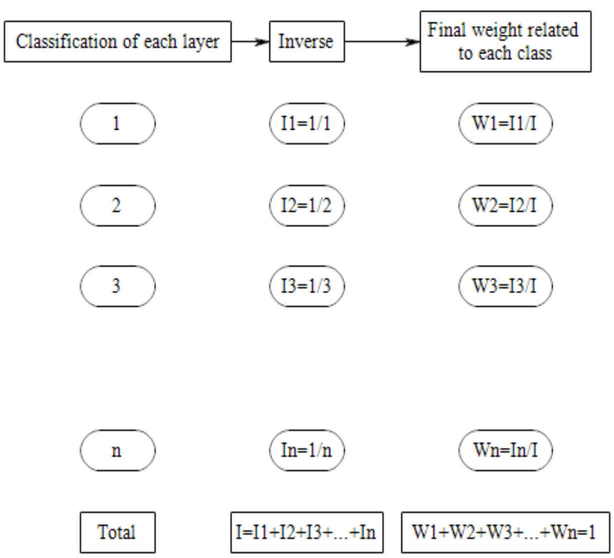


Figure 10 Final weight of each class among all classes for each constraint layer

These weights of constraint parameters will be used in process of determining the best candidate by using AHP technique in phase 3 of current research.

4.0 COST CATEGORY

This section investigates the phase 2 of proposed methodology for determining the best highway candidate. In this paper based on case study conditions, four cost function categories are considered and expanded, including: length-dependent cost, structural cost, location-dependent cost and earthwork cost. The calculated costs in this paper are estimated by assuming some of the parameters and approximating. These cost functions are extracted from research conducted by Sajjadi [6] and merely used for determining the comparable weights of costs related to each highway candidate, which are required in the Analytic Hierarchy Process (AHP) technique.

4.1 Length-dependent Costs

In this research, the concept of length-dependent cost encompasses costs that have a direct relationship with the decrease or increase of highway length and are divided into three categories as follows:

✓ Pavement cost including sub-base, base and pavement surface costs

$$C_{len(p)} = L \times upc \qquad (1)$$

where
$C_{len(p)}$ = pavement cost related to length-dependent cost
upc = unit pavement cost
L = length of highway candidate

✓ Costs related to signs and signals

$$C_{len(s)} = L \times usc \qquad (2)$$

where
$C_{len(s)}$ = signs and signals costs related to length-dependent cost
usc = unit sign cost
L = length of highway candidate

✓ Costs associated with safety and facilities such as guardrails, lighting systems, etc.

$$C_{len(i)} = L \times uic \quad (3)$$

where
$C_{len(i)}$ = safety guard rails and facility costs related to length-dependent cost
uic = unit installation cost
L = length of highway candidate

The total cost related to the length of each highway candidate can be defined according to Equation (4).

$$TC_{Len} = C_{Len(p)} + C_{Len(s)} + C_{Len(i)} \quad (4)$$

4.2 Location-dependent Cost

According to the explanations provided in the research conducted by Sajjadi [6], the following equation is generated for location-dependent cost.

$$TC_{loc} = \sum_{i=1}^{ngp} \alpha_i \times ugc \times A_{gi} + \sum_{i=1}^{nfp} \alpha_i \times ufc \times A_{fi} \quad (5)$$

where
ugc = unit cost of standard land parcel with garden land use located near the city boundary based on real estate agents
ufc = unit cost of standard land parcel with farmland land use located near the city boundary based on real estate agents
A_{gi} = fractional area of the i^{th} land parcel with garden land use located in highway alignment regions
A_{fi} = fractional area of the i^{th} land parcel with farmland land use located in highway alignment regions
α_i = an index based on the case study conditions and the distance of the i^{th} land parcel to the city boundary
ngp = number of garden land parcels
nfp = number of farmland land parcels

α_i can be obtained by using a questionnaire (asking real estate agents questions on the range of land parcel cost in the case study region). For example, for the present case study the following amounts were acquired:

$\alpha \cong 1$ If land parcel is located less than 2 kilometers from the city boundary
$\alpha \cong 0.85$ If land parcel is located between 2 kilometers and 5 kilometers from the city boundary
$\alpha \cong 0.75$ If land parcel is located more than 5 kilometers from the city boundary

4.3 Structural Costs

Structural cost is another cost group influencing in selection of optimal highway candidate and includes costs related to bridges, tunnels, retaining walls, culverts, etc. This cost for various highway candidates in accordance with their geographical situations may vary and should be calculated separately for each candidate. Structural cost is generally divided into three major categories as follows:

- ✓ Costs related to bridges

$$C_{Str(b)} = \sum_{j=1}^{nob} L_{b(j)} \times ubc \quad (6)$$

where
$C_{Str(b)}$ = total bridge cost along a highway candidate
$L_{b(j)}$ = length of the j^{th} bridge
ubc = unit bridge cost based on bridge volume
nob = number of bridges along the highway alignment region

- ✓ Costs related to tunnels

$$C_{Str(t)} = \sum_{j=1}^{not} l_{t(j)} \times utc \quad (7)$$

where
$C_{Str(t)}$ = total tunnel cost along a highway alignment region
$l_{t(j)}$ = length of j^{th} tunnel
utc = unit tunnel cost based on tunnel length
not = number of tunnels along a highway alignment region

- ✓ Costs related to retaining walls

$$C_{Str(w)} = \sum_{j=1}^{now} A_{w(j)} \times uwc \quad (8)$$

where
$C_{Str(w)}$ = total retaining wall cost along highway alignment areas
$A_{w(j)}$ = area of j^{th} retaining wall
uwc = unit retaining wall cost
now = number of retaining walls along highway alignment areas

The total cost related to structures on highways can be defined according to Equation (9).

$$TC_{Str} = C_{Str(b)} + C_{Str(t)} + C_{Str(w)} \quad (9)$$

4.4 Earthwork Costs

Earthwork volume is obtained in this paper by using the average end area method and the Equation (10) is for determining the total earthwork cost.

$$C_E = V_c \times ucc + V_f \times ufc \quad (10)$$

where
C_E = earthwork cost for each candidate ($)
Vc = total cut volume of each candidate
Vf = total fill volume of each candidate
ucc = unit cost of cut ($\$/m^3$)
ufc = unit cost of fill ($\$/m^3$)

4.5 Cost Weights

In the previous sections, four functions related to highway costs were presented and expanded based on the case study conditions. All of these cost functions are used in the current study in order to determine the weights of the cost categories for each highway candidate and weight of each cost category. Basically, these cost functions are for obtaining the weights of cost categories relative to each other (the weight of each cost category) as well as obtaining the weight of each candidate based on each cost category.

In this study, a method for determining the cost weights is suggested. To determine the AHP weight of each candidate based on each cost category, the cost of each defined candidate by phase 1 should be initially calculated using the provided cost functions. Afterward, the AHP weight of each candidate will be obtained based on the flowchart provided in Figure 11.

The AHP weights of all highway candidates should be calculated using the above flowchart based on every cost category as investigated in previous sections. These weights will be applied to the process of determining the best highway candidate using the Analytic Hierarchy Process technique.

To determine the AHP weight of each cost category relative to each other, the process shown in the flowchart in Figure 12 can be used. To use this process, the average of each cost category (location-dependent cost, earthwork cost, length-dependent cost and structural cost) needs to first be calculated for all candidates, after which the process below can be used.

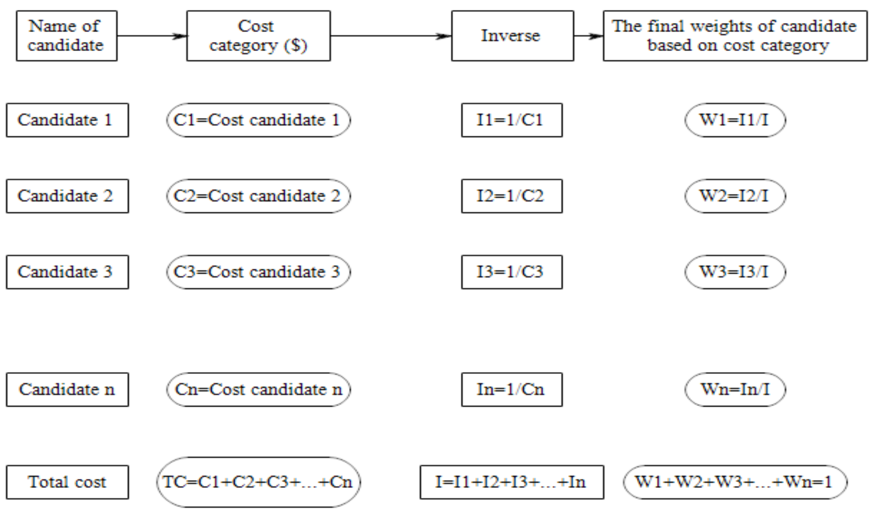


Figure 11 Flowchart for obtaining the weight of each candidate based on each cost category

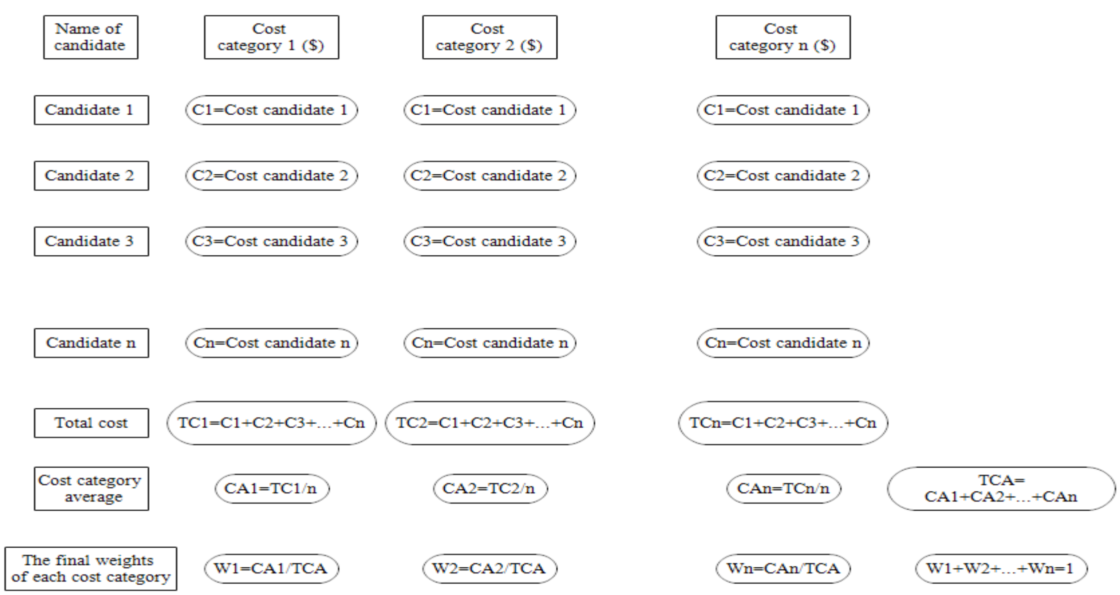


Figure 12 Flowchart of AHP weight for each cost category related to each other

These cost categories' weights and cost weights of all highway candidates will be used in the process of determining the best highway candidate using the AHP technique.

5.0 SAFETY PARAMETERS

This section also investigates the phase 2 of proposed methodology for determining the best highway candidate. Several geometric characteristics of highway alignment can play an important role in reducing road accidents, e.g., horizontal curve, vertical curve, horizontal and vertical curve interference, direct path, tunnels, bridges, etc. The effects of these geometric highway alignment characteristics have been investigated worldwide in several research works by Gupta *et al.* [7], Walmsley *et al.* [8], Ahadi [9], Anastasopoulos *et al.* [10], Elvik [11], Lamm *et al.* [12] and Sajjadi *et al.* [13]. After a comprehensive study of the factors affecting road accidents in the study area, the three main parameters investigated in the current research are: the number of horizontal and vertical curve interferences, the number of horizontal curves and the number of vertical curves. The weights of each safety parameter relative to each other in the current study were obtained through questionnaires, which were developed based on the AHP technique. In this research, 15 participants were attended, who had good experience in highway safety. Table 1 presents the final weights of the safety parameters obtained from the questionnaires.

Table 2 Final safety parameter weights based on the questionnaires

Criteria Name	AHP Weight %
Number of horizontal curve	18.18
Number of vertical curve	9.09
Number of horizontal and vertical curve interference	72.73

5.1 Weight of Each Highway Candidate Based on Each Safety Parameter

To determine the weight of each highway candidate in terms of safety parameters, the flowchart provided in Figure 13 can be employed. In this method, each safety parameter for each highway candidate needs to be first extracted, and then the weight of each candidate will be obtained using this flowchart process.

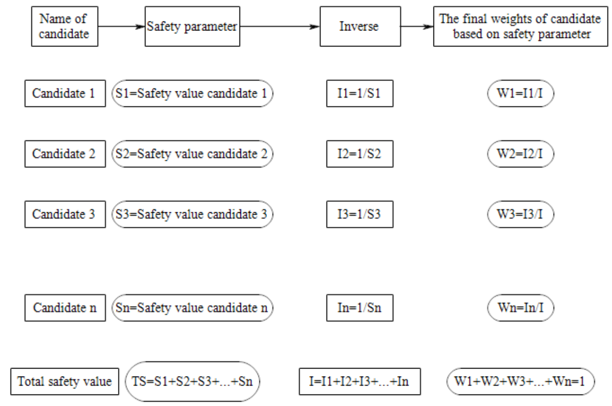


Figure 13 Flowchart of AHP weight for each candidate based on each road safety parameter

These AHP weights are associated with safety parameters, and the safety parameters' weights will be utilized in the process of determining the best highway candidate through the AHP technique in the next phase.

6.0 AHP FOR DETERMINING THE BEST highway CANDIDATE

This section is related to phase 3, proposed methodology for determining the best highway candidate. Organizing and analyzing complex decisions is facilitated by the Analytic Hierarchy Process (AHP), because it is a structured method. This technique was introduced by Thomas L. Saaty in the 1970s [14] and is based on mathematics and psychology. Over time, this method has been extensively studied and refined. This technique is also applied in the current research to determine the best highway candidate among several candidates, with special focus on the cost and safety parameters. The weights of all highway candidates related to every constraint, cost and safety parameters as well as the weights of all constraint, cost and safety parameters are required for this method. The weights for the present research were obtained using the equations and flowcharts in Figures 8-13 and Tables 1-2 respectively.

The weight of constraint, cost and safety relative to each other can be vary based on conditions of road project and case study region. In this research the amount of them are considered identical or in the other word, for each one the weight is equal to 0.3333. Used hierarchy of AHP for provided example in terms of the constraint, cost and safety criteria is shown in Figure 14.

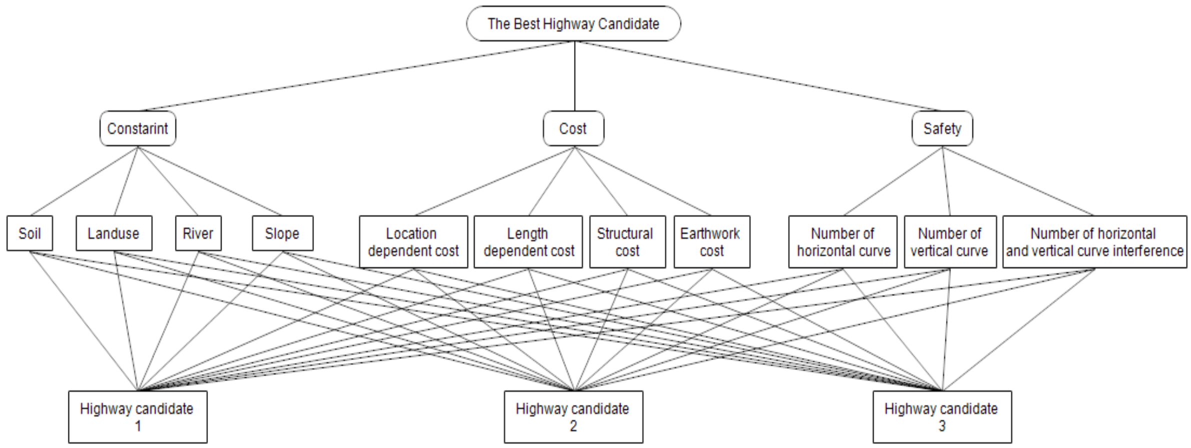


Figure 14 Used hierarchy for provided example based on constraint, cost and safety parameters

The above hierarchy can be modeled by Expert Choice software which working based on AHP technique. An example is investigated next, where the proposed methodology is applied to determine the best highway candidate among candidates defined in phase 1 for the case study region. The consistency ratio in the current example analysis is 0.007, and based on the AHP technique definition it is acceptable.

7.0 EXAMPLE

This example is to demonstrate how working the proposed methodology and its validation with a real world case study. In this example, three highway candidates which were created in phase 1 of current research will be used in process of proposed methodology. Defined candidates from origin to destination point are shown in Figure 15 together. The final aim of this example is to simultaneously determine the best candidate in terms of constraint, cost and safety criteria. Final weight of each class among of all candidates for layers soil, river, slope and land use are shown in Tables 3-6, which are obtained by using flowchart provided in Figure 9.

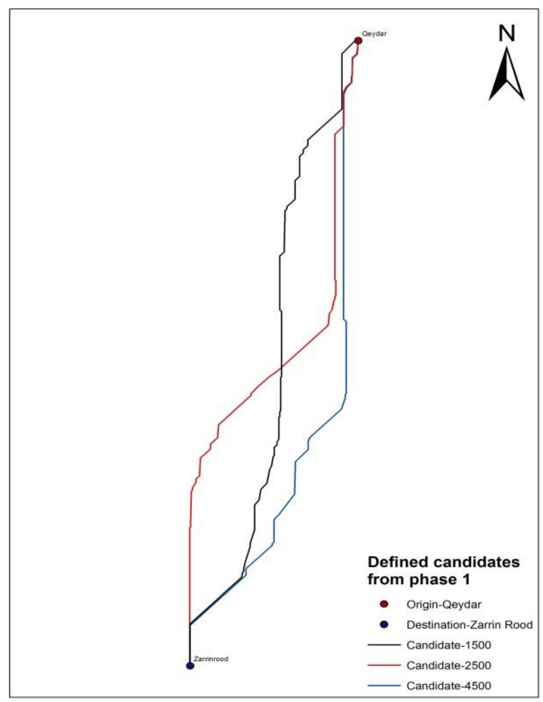


Figure 15 Three highway candidates between Qeydar and ZarrinRood defined for the current example

Table 3 Final weight of each class among of all candidates for soil layer (according to flowchart provided in Figure 9)

Name of candidate	Weight class 1	Weight Class 2
Candidate-1500	0.326648841	0.353174603
Candidate-2500	0.343582888	0.302910053
Candidate-4500	0.329768271	0.343915344
Total	1	1

Table 4 Final weight of each class among of all candidates for river layer (according to flowchart provided in Figure 9)

Name of candidate	Weight Class 5	Weight class 6	Weight class 7	Weight class 8	Weight class 9	Weight class 10
Candidate-1500	1	0.63212435	0.5662020	0.3050391	0.2573587	0.359441
Candidate-2500	0	0.36787564	0.4337979	0.3265397	0.2927750	0.384742
Candidate-4500	0	0	0	0.3684210	0.4498662	0.255816
Total	1	1	1	1	1	1

Table 5 Final weight of each class among of all candidates for slope layer (according to flowchart provided in Figure 9)

Name of candidate	Weight class 1	weight class 2	weight class 3	weight class 4	weight class 5	weight class 6	weight class 7	weight class 8
Candidate-1500	0.302	0.613	1	0.875	1	1	0.282	1
Candidate-2500	0.341	0	0	0.0877	0	0	0.557	0
Candidate-4500	0.3569	0.3869	0	0.036	0	0	0.1599	0
Total	1	1	1	1	1	1	1	1

Table 6 Final weight of each class among of all candidates for land use layer (according to flowchart provided in Figure 9)

Name of candidate	Weight class 1	weight class 4	weight class 5	Weight class 9
Candidate-1500	0	0.3265	1	0.3608
Candidate-2500	1	0.3287	0	0.3069
Candidate-4500	0	0.3447	0	0.3321
Total	1	1	1	1

Tables 7-10 show the final weight of each class among all classes for each used constraint layer in this example which are obtained by using flowchart provided in Figure 10.

Table 7 Final weight of each class among all classes for soil layer (according to flowchart provided in Figure 10)

Used Class	Inverse	Weight
1	1	0.666667
2	0.5	0.333333
Total	1.5	1

Table 8 Final weight of each class among all classes for river layer (according to flowchart provided in Figure 10)

Used Class	inverse	Weight
5	0.2	0.236508681
6	0.166667	0.197090568
7	0.142857	0.168934772
8	0.125	0.147817926
9	0.111111	0.131393712
10	0.1	0.118254341
Total	0.845635	1

Table 9 Final weight of each class among all classes for slope layer (according to flowchart provided in Figure 10)

Used Class	Inverse	Weight
1	1	0.367539
2	0.5	0.183769
3	0.333	0.12239
4	0.25	0.091885
5	0.2	0.073508
6	0.17	0.062482
7	0.1428	0.052485
8	0.125	0.045942
Total	2.7208	1

Table 10 Final weight of each class among all classes for land use layer (according to flowchart provided in Figure 10)

Used Class	Inverse	Weight
1	1	0.640569395
4	0.25	0.160142349
5	0.2	0.128113879
9	0.111111	0.071174377
Total	1.561111	1

Table 11 shows the unit cost of each cost parameter which are obtained from manual price for Iran road construction. These unit costs are constant for all highway candidates and therefore the amount of them cannot change the final result of proposed methodology.

Table 11 Unit cost of each cost parameter

Cost category	Cost parameter name	Unit cost ($)
Location dependent cost	Farming land	10
	Garden	50
	National land	0
	Mix farming land and national land	5
	Mix farming land and garden	30
Earthwork cost	cost of cut	3
	cost of fill	3
Structural cost	bridge cost based on bridge volume	1000
	tunnel cost based on tunnel length	10000
	retaining wall cost	400
Length dependent cost	pavement cost	100
	sign and signal cost	50
	safety guards and facility cost	40

Tables 12-13 show the specification of each candidate for each cost category in this example which are obtained by using ArcGIS and Civil 3D software.

Table 12 Location properties obtained with ArcGIS software for the three candidates

Candidate-1500			Candidate-2500			Candidate-4500		
Land use	**Alfa**	**Total Area (m^2)**	**Land use**	**Alfa**	**Total Area (m^2)**	**Land use**	**Alfa**	**Total Area (m^2)**
Farming land	1.00	102,600	Mix farming land and garden	1.00	152000	Mix farming land and garden	1.00	152000
Garden	1.00	49,400	Mix farming land and garden	0.85	19000	Mix farming land and garden	0.85	15200
Garden	0.85	15,200	Farming land	0.85	209000	Farming land	0.85	212800
Farming land	0.85	212,800	Farming land	0.75	95000	Farming land	0.75	68400
Farming land	0.75	604,200	Mix farming land and garden	0.75	83600	Mix farming land and garden	0.75	110200
Mix farming land and national land	0.75	592,800	Farming land	0.75	1045000	Farming land	0.75	900600
Farming land	0.75	577,600	Mix farming land and national land	0.75	433200	Mix farming land and national land	0.75	737200
Farming land	0.75	125,400	National land	0.75	171000	Farming land	0.75	630800
Farming land	0.75	315,400	Mix farming land and national land	0.75	144400	Farming land	0.85	216600
Mix farming land and garden	0.75	76000	Farming land	0.75	478800	Garden	0.85	11400
Farming land	0.75	152000	Farming land	0.85	212800	Garden	1.00	53200
Farming land	0.85	155,800	Garden	0.85	15200	Farming land	1.00	98800
Mix farming land and garden	0.85	72,200	Garden	1.00	49400	--------	----	------
Mix farming land and garden	1.00	57,000	Farming land	1.00	102600	-------	----	------
National land	1.00	11,400	---------	----	------	--------	----	------
Mix farming land and garden	1.00	83,600	---------	----	------	--------	----	------

Table 13 Specifications of each highway candidate extracted from Civil 3D software

Name of Candidate	Total length (m)	Total bridge length (m)	Total tunnel length (m)	Total retaining wall area (m^2)	Total cut volume (m^3)	Total fill volume (m^3)
Candidate-1500	42168.3124	143.75	0	0	5,739,088.36	6,477,345.82
Candidate-2500	42263.5101	122.85	0	0	2,563,764.95	3,619,957.98
Candidate-4500	42243.776	74.7	0	0	1,012,294.27	1,132,571.51

According to the above-mentioned cost specifications of these three highway candidates, the weights provided in Tables 14-15 for each highway candidate and cost category are obtained based on flowcharts provided in Figures 11 and 12 respectively.

Table 14 Final weights of each highway candidate based on each cost category provided

Candidate Name	Location dependent cost	Earthwork cost	Length dependent cost	Structural cost
Candidate-1500	0.3252	0.1154	0.3338	0.2442
Candidate-2500	0.3432	0.2278	0.3330	0.2858
Candidate-4500	0.3316	0.6568	0.3332	0.47

Table 15 Final weights of each cost category

Cost category	Location dependent cost	Earthwork cost	Length dependent cost	Structural cost
Final weight	0.5099	0.3511	0.1371	0.0019

Table 16 shows the specifications of these three highway candidates based on the safety parameters presented in the current research through ArcGIS software.

Table 16 Specifications of each highway candidate based on the safety parameters provided

Name of Candidate	Number of horizontal curve	Number of vertical curve	Number of horizontal and vertical curve interference
Candidate-1500	47	55	17
Candidate-2500	37	64	23
Candidate-4500	27	49	17

According to the above-mentioned safety specifications of the three highway candidates, the safety weights provided in Table 17 for each highway candidate are obtained according to flowchart provided in Figure 13.

Table 17 Final weights of each highway candidate based on each safety parameter

Name of Candidate	Number of horizontal curve	Number of vertical curve	Number of horizontal and vertical curve interference
Candidate-1500	0.2493	0.3354	0.3651
Candidate-2500	0.3167	0.2882	0.2698
Candidate-4500	0.434	0.3764	0.3651

The final weights of all safety parameters relative to each other are obtained from the questionnaire expressed in Table 2.

After determining the final weights of the highway candidates and final weights of all constraint, cost and safety parameters relative to each other, all weights found are input to the Expert Choice software, and the final weights of each highway candidate based on constraint, cost and safety will be the output. The final result is illustrated as a bar chart in Figure 16, and it signifies that the best highway candidate (candidate 4500 with weight of 0.356 in current example) can satisfy all constraint, cost and safety parameters which are used in this example simultaneously.

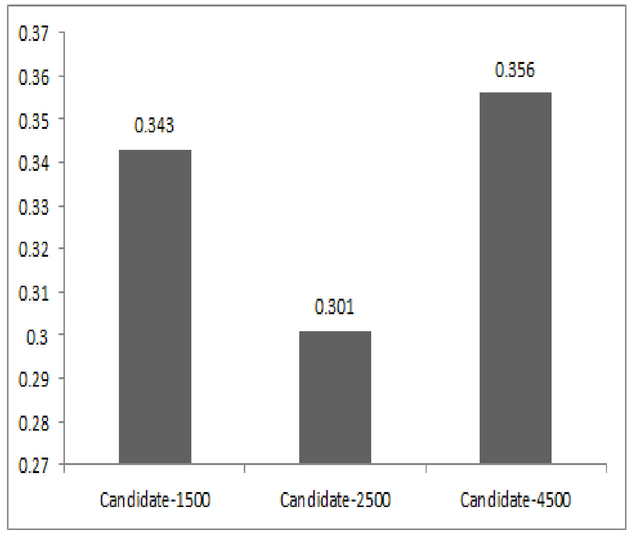


Figure 16 Final AHP weights of each highway candidate based on constraint, cost and safety parameters

Figure 17 displays the sensitivity graph of three highway candidates in terms of constraint, cost and safety parameters.

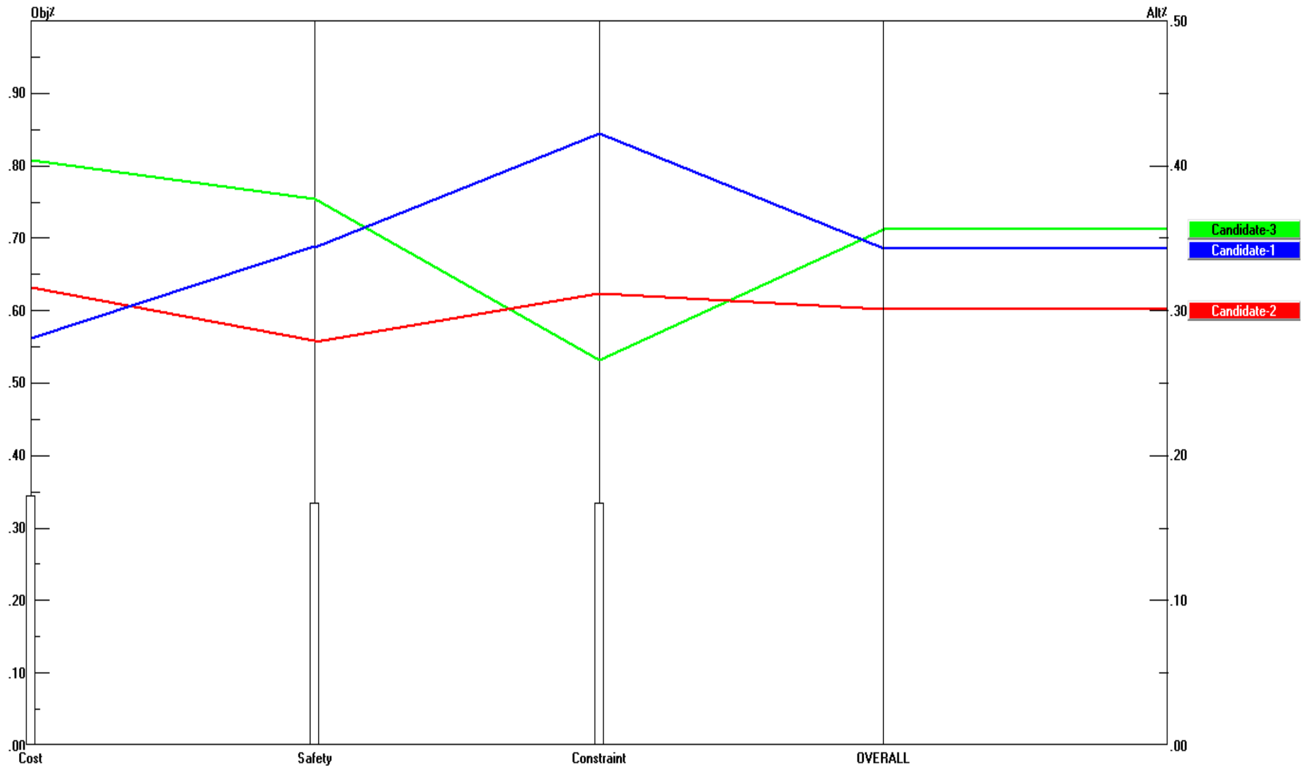


Figure 17 Sensitivity graph of highway candidates based on their weights

8.0 CONCLUSION

In this paper, an attempt is made to develop a multi-criteria analysis methodology to determine the best highway candidate, with specific focus on constraint, cost and safety parameters. The multi-criteria analysis methodology is based upon the analytical hierarchy process technique, which systematically determines the best highway candidate according to the effect of each parameter such as constraint, safety and costs among several candidates which are created based on constraint layers. Used constraint layers in current paper are soil, river, slope and land use which are selected based on case study conditions. Final candidates created from different buffer size have different cost and safety values and a good condition for constraints in that buffer size. The number and size of each buffer is dependent to the study area and importance of road project. Whatever the number of buffers is greater and the size of them is smaller, the best candidate determined with this methodology will be in better conditions. Regarding highway costs in the current research based on case study region, four categories are expanded and organized, including: length-dependent cost, earthwork cost, location-dependent cost and structural cost. In terms of highway safety in the current work, the three parameters investigated are the number of horizontal and vertical curve interferences, the number of horizontal curves and the number of vertical curves.

All cost and safety parameters presented in this research are basically deemed comparable values to be used in the proposed methodology for determining the best highway candidate. The final highway candidate determined as the best candidate through the proposed methodology can satisfy all related parameters in determining the optimal highway candidate concurrently.

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