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Research Paper

Selection of the best alternative for a road project to replace a section in a flood-prone area using GIS and AMC tools

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ABSTRACT

Decision-making involves the selection from various possible alternatives and generally implicates huge financial resources. In addition, one characteristic of a territory making it difficult to make a decision is its multi-criteria aspect. These multi-criteria generally have antagonistic effects and analytical methods are most congruent for solving this kind of difficult decision-making situation. The work presented in this article focuses on the problem of decision-making in order to identify the most favorable road alignment with regard to a series of topographical, geometric, geological and economic criteria. The main goal of this study is to select the best road alignment project to replace part of the road section of the CW 42 connecting the city of Sidi Belattar to National Road 90 (RN 90) using GIS and AMC tools. This road section has been blocked several times in recent years during rare winter flooding. The proposed approach deals with the following points: First, determination of the relevant criteria using GIS, then evaluation and classification of the various alternatives by applying the AHP method using AMC Expert-choice software and PROMETHEE-GAIA algorithms (laboratory-developed web.d-sight software, coded SMG, ULB). Four variants were recommended to replace the vulnerable section. From these four variants a classification was made, according to the two methods AHP and PROMETHEE. The calculated consistency of the results confirms the effectiveness of the proposed approach. Finally, Alternative 2 and Alternative 1 were ranked first by both AHP and PROMETHEE methods and are therefore a recommended choice. This work aims at helping decision makers to rank four road projects of the study area in order to replace the most vulnerable section.

1 Introduction

The problem of choosing the best road alignment project is complex and involves numerous different criteria that may have possible contradictory effects and unequal importance [1-3]. Controlling this complexity requires the use of powerful analytical methods, techniques and tools capable of managing and analyzing geolocalized data of various types and origins.

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Geographic Information System (GIS) has powerful tools for manipulating, managing and analyzing spatial data that can contribute to the collection of information, the production of derived information and the processing of a large volume of data [4],[5]. However, GIS does not incorporate decision-maker preferences to make a choice in a context of objective assessment and conflicting criteria. In addition, the decision maker takes into account several criteria for judging actions (alternatives), which is not possible with GIS. These restrictions limit GIS to assist with decision-making. Multi-criteria methods of decision-making help are adequate for processes involving collective choices where the viewpoints are contradictory. Spatial aggregation of multi-criteria methods helps reduce alternatives for best selection and to make a decision in different conflicting criteria situations where no option is perfect. This is why the use of GIS technologies and multi-criteria analysis methods together is essential to drive GIS towards real decision-making tools [6-8].The main purpose of this study is to adapt GIS, a Analytic hierarchy process (AHP) and a specialized tool in AMC (web-d-Sight) as well as PROMETHEE-GAIA algorithms in order to propose the best road alignment project among four road alignments with a view to replace a connected part of the vulnerable section between the CW42 and CW60 Wilaya (or Provincial) roadways connecting Sidi Belattar to the national road (RN 90). This section was totally flooded during the last decade and especially during the flood of January 17, 2017 as shown in Figure.1. A geo-referenced database on the study area allowed us to extract the basic information to categorize the different alternatives.

Fig.1 - Flood January 2017 (overflow of Cheliff wadi bed on the CW42 and CW60)

2 Problematic context and contribution

Territorial problems are multidimensional and multidisciplinary requiring the definition of several conflicting criteria of varying importance and dealing with a considerable amount of quantitative and qualitative data [9]. The bibliographic study in the field of road infrastructure reveals that there exists no approach based on spatial analysis methods which incorporates the different aspects such as the topographical, geological, and economic aspects and uses a multi-criteria method to structure the components and evaluate all the criteria of the problem according to their weighting. It is this observation that prompted us to consider examining the contribution of multi-criteria modeling by considering the approaches that can be taken to address the specific issues and challenges of managing geolocalized road infrastructures in locations vulnerable to flood risks. Resolving such problems involves finding a common decision for all actors **[10],[11].**Different approaches to deal with a multi-criteria decision-making process do exist; however, each approach has its advantages and disadvantages and focuses on certain aspects at the expense of others [12].

The need for multi-criteria analysis (MCA) arose in order to find a reasonable compromise in a complex choice situation. Multi-criteria decision support is intended to provide a decision-maker with tools to move forward in decision-making where different points of view are to be considered [13]. MCA requires the use of criteria (factors or constraints) that reinforce or reduce the relevance of a particular alternative to the activity under consideration [14]. GIS technology is particularly suitable for map development. These perspectives led us to propose a multi-criteria modeling combining the functionalities offered by GIS and the hierarchical multi-criteria method to apprehend the choice of the best road project among four projected road tracks which will allow the substitution of a localized section in a flood-risk area. In the present work, the PROMETHEE algorithm is used in the recognition and prioritization of evaluation criteria and in the classification of the four road projects. There are at least four arguments to adopt PROMETHEE for this research. Firstly, it is flexible in accepting data from various fields such as topography, geometry, geology and economy of the different road projects. Secondly, qualitative and quantitative data can be processed together. Thirdly, it can provide two types of classification with and without incomparability, which helps to identify the strengths and weaknesses of each alternative. Finally, we use the GAIA tool, which admits a visual representation of the problem of support decision, to interpret associations, inter-dimensional conflict and inter-actors and to ensure discussion and agreement between the stakeholders. A version of the MCA Web.d-Sight tool [15] based on PROMETHEE-GAIA methodology is used in this study. The AHP (analytic hierarchy process) method based on the single criterion of synthesis aiming at constructing a function synthesizing all the criteria is applied for comparison. This choice is mainly due to its simplicity, ease of understanding to solve a wide range of unstructured problems, flexibility as well as ability to bring quantitative and qualitative criteria into the same decision-making framework [16-18]. It will be supplemented by the Weight Sum Model (WSM) method for the definition of calculation formulas for the concepts of aggregate impact and weighted criticality.

3 Study area

The work area chosen to implement our study is the Sidi Belattar region in the Wilaya of Mostaganem (west of Algeria) situated between latitude 36 ° 01'36 North and longitude 0 ° 16'10 East. It covers an area of 8800 ha (Figure 2) with an estimated population of 6794 inhabitants (RGPH 2014). It is part of the Dahra Mountains located in the centre of a rich agricultural region. It is limited to the North by a forest and the Kerrada dam, to the south by the Chéliff River, to the East by RN 90 road and to the west by the Sidi Belattar urban area. The geomorphology is marked by a corrugated peneplain. The dominant vegetation is a scattered forest. The region is semi-arid with a dry and hot climate with an average annual rainfall of 360 mm. The hydrographic network is dense with the main river Cheliff geo-located in the south of the study region.

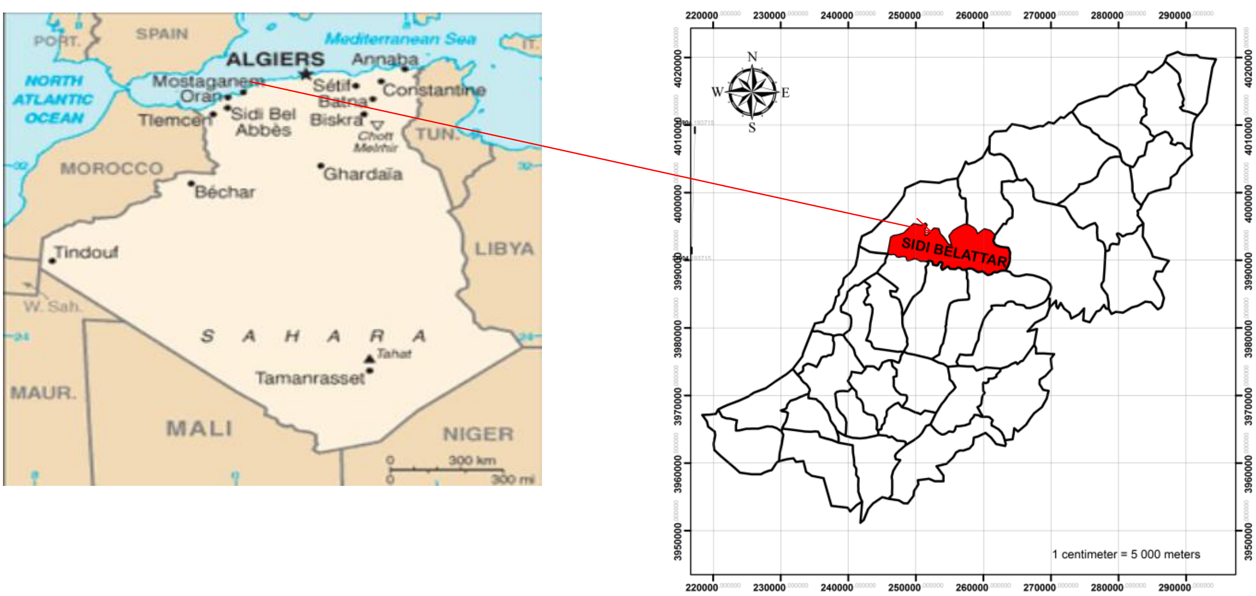

Fig. 2- Location of the study area

4 Equipment and materials used

The approach applied in this study requires the incorporation of spatial data, a topographic map, a 1: 50000 geological map and alphanumeric data relating to the economic aspect, civil engineering works, etc. The inventory and analysis of these data led to the establishment of a spatially referenced database .Arc-Map, Web.d-sight, Expert-choice, Google earth were used for data processing and implementation of a geographic information system of the study area. Data was organized, exploited and processed to extract essential information to multi-criteria analysis. Figure 3 shows the existing road network.

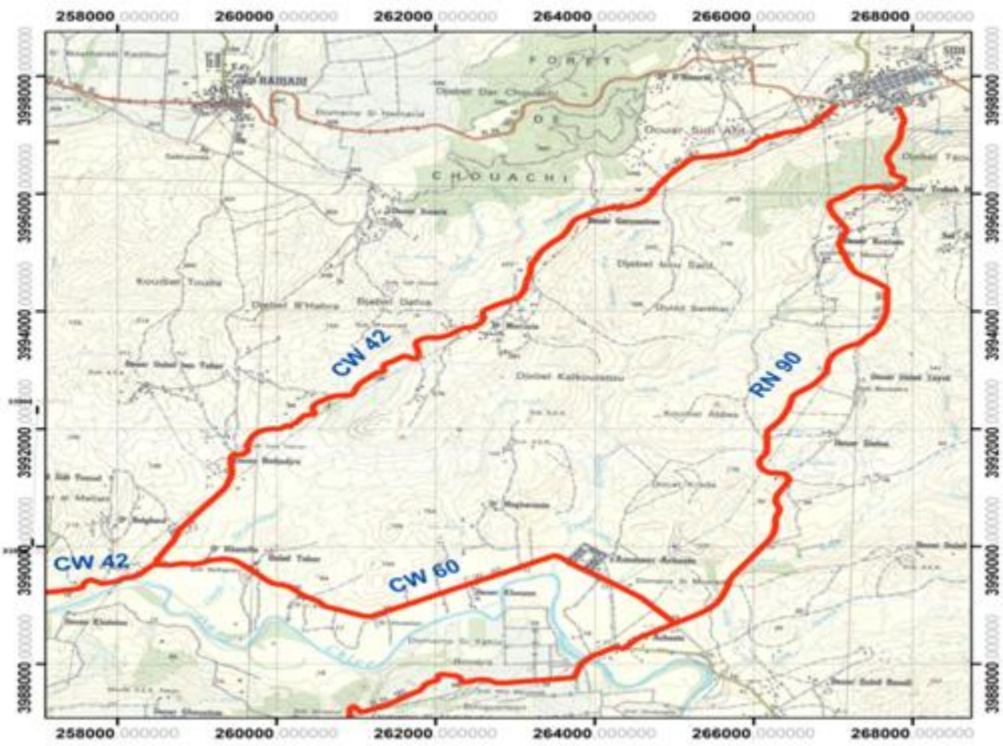

Fig.3- Presentation of the existing road network in the study area

5 Methodological approach

In this section, we provide an overview of AHP and PROMETHEE techniques for solving multi-criteria problems. In addition, the advantages and limitations of both methods are briefly described.

5.1 AHP Method

The analytic hierarchy method (AHP), developed by Saaty [17-20], is a powerful multicriteria decision-making tool that has been used in numerous applications in various fields of economics, politics and engineering. AHP can increase the interference and promise of individuals in decision-making processes. AHP approach is inspired by what is happening in the human brain. The pairwise comparison requirement in AHP is considered an advantage as it forces policy makers to think more strongly about the weight of different factors and analyze situations at deeper levels. Another advantage of AHP is its ability to measure quality and quantity indicators using mental preferences, expertise and objective information. By arranging top-down criteria in a decision tree, AHP systematically considers complex issues, including incorporating the opinions of experts and decision-makers. AHP is a credible method for calculating the weight of each criterion since it is based on the views of decision makers rather than the decision matrix. AHP also allows for sensitivity analysis on criteria and sub-criteria. A unique feature of AHP is the ability to calculate the compatibility / incompatibility of decisions made by decision makers. In a first step, AHP subdivides a complex decision. By breaking down the problem into a hierarchical structure, composed of decision elements (criteria and alternatives) with at least three levels:

- General objective at the highest level;
- Multiple criteria that determine alternatives at the intermediate level;
- Alternatives at the lowest level.

The second step is comparing alternatives and criteria. Once the problem is analyzed and hierarchical levels are formulated, preferences are determined at each level according to the relative importance of each criterion. At each level, pairwise comparison is one of the criteria for recognizing the impact of each criterion compared to certain criteria at higher levels. Pairwise comparisons are performed using a standard scale shown in Table 1.

Table 1- Scale proposed by SAATY [20]

Intensity of importance	Explanation
1	Equal importance: two activities contribute equally to the objective
3	Weak importance of one another: experience and judgment slightly favor one activity over another
5	Essential or strong importance: experience and judgment strongly favor one activity over another
7	Demonstrated importance: an activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance: The evidence favoring an activity over another is of the highest possible order of affirmation
2,4.6.8	Intermediate values between the two adjacent judgments: when a compromise is needed

Suppose that $C = \{C_j : j = 1,2 \dots, n\}$ is the set of criteria. As seen in Equation (1), the result of pairwise comparison over n criteria is summarized in an nxn matrix where elements, aij (i,j=1,2,…,n), represent relative weights of criteria. In AHP, pair wise comparison is made by more than one decision maker and all of these opinions are taken into account. In this case geometric mean can be used as seen in equation (2).

$$\begin{bmatrix} a11 & a12 \cdots & an1 \\ \vdots & \ddots & \vdots \\ an1 & an2 \cdots & ann \end{bmatrix}, a_{ii}=1,\ a_{ji}=1/a_{ij},\ a_{ij}\neq 0 \quad (1)$$

$$a'_{ij} = \left(\prod_{l=1}^{k} a_{ijl}\right)^{\frac{1}{k}},\ l=1,2,\dots,k;\ i,j=1,2\dots,n;\ i\neq j \quad (2)$$

Where k is the number of decision makers in the last step, the mathematical process begins with the normalization and determination of the relative weights for each matrix. The relative weights are defined by the eigenvector λ_{max}:

$$A'\omega = \lambda_{max}\omega \quad (3)$$

The matrix A has the rank 1, if the comparisons by pairs are entirely harmonious (λ_{max}). Here, the weights can be obtained by normalizing a row or a column. For the approval of the weighting results, it is therefore essential to have a means to measure the consistency of the issued judgments. In most cases, greater consistency in judgments implies better judgments and that the estimates of the weights relating to the criteria adopted are all the more reliable. Thus, the coherence index measures the reliability of the comparison expressed in coherent judgments. The greater the consistency index becomes, the more inconsistent the judgments that have been expressed in the comparison matrix and vice versa. The coherence index (CI) is expressed by Expression (4):

$$IC = {}^{(\lambda_{\max - N})}\!\big/_{(N-1)} \quad (4)$$

Where N: is the number of elements compared and λmax, a value calculated on the basis of the average of the Saaty matrix values of the eigenvectors. The experimentation established by [21] made it possible to define the coherence ratio as being the ratio of the coherence index calculated on the matrix corresponding to the judgments of the decision makers and of the random index (IA) of a matrix of the same dimension. Therefore, the coherence ratio can be interpreted as the probability that the matrix is completed randomly. It is given by Expression (5):

$$RC = {}^{IC}\!/_{IA} \quad (5)$$

Where IA: is the random index set according to the number of criteria (Table 2).

According to SAATY, if RC is greater than 0.1, there is an inconsistency in the paired comparisons and the matrix resulting from the comparisons will have to be reevaluated. For our case, the consistency ratio RC = 0.03 <0.1. It is less than 0.1, which allows us to affirm that the judgments of criteria assessment were coherent.

Table 2 - Random indices based on the number of compared elements

Number of compared items	2	3	4	5	6	7	8	9	10
Random Index (IA)	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

5.2 The PROMETHEE Method

The Preference Ranking Organization Method for Enrichment Evaluation “PROMETHEE” method is one of Multicriteria Decision Analysis (MCDA) which was firstly developed by Brans [22] then extended by Brans and Vincke [23] , Brans et al. [24] and Brans and Marshal [25, 26]. It has previously been used successfully in various cases. The PROMETHEE Method needs the evaluation table where the whole of actions should be evaluated using different criteria. A specific preference function needs to be defined (Pj (a, b)) that translates the deviation between the evaluations of two alternatives (a and b) on a particular criterion (gj) into a degree of preference ranging from 0 to 1. This preference index is a non-decreasing function of the observed deviation between the scores of the alternatives on the considered criterion (fj (a)-fj (b)) as shown in equation (6).

$$P_j(a,b) = G_j\{f_j(a) - f_j(b)\} \tag{6}$$

Several preferences have been cited in the literature but just six among them were selected to determine the function of preference, i.e., usual shape, U-shape function, V-shape function, level function, linear function and Gaussian function. After the determination of the specific function, the determination of the weights of the criteria is paramount because the PROMETHEE approach does not determine the weight for a large number of criteria. In this case, it is recommended to use several methods, particularly the comparison by pair method.

In our study, the weight of the criteria is determined by AHP. Using this method, a preference index π (a, b) can be calculated taking all the criteria into account (eq7).

$$\pi(a,b) = \sum_{j=1}^{k} w_j P_j(a,b) \tag{7}$$

The preference index is calculated from two sub parameters: a positive preference index $\emptyset^+$(a) and a negative preference index $\emptyset^-$(a). For each alternative, the calculation of the preference index shows whether it is outranking in relation with the others. The net preference index is calculated from the subtraction of the two preference indices (equations 8 and 9).

$$\emptyset^+(a)\frac{1}{n-1}\sum_b \pi\,(a,b) \tag{8}$$

$$\emptyset^-(a)\frac{1}{n-1}\sum_b \pi\,(b,a) \tag{9}$$

The interpretation of the obtained value shows a strong correlation between the higher index values and the most important alternative. The classification of the different alternatives therefore follows a positive correlation with the net preferences indices $\emptyset$ (a) (equation10).

$$\emptyset(a) = \emptyset^+(a) - \emptyset^-(a) \tag{10}$$

Three principal PROMETHEE tools can be used to resolve the evaluation problem:

- PROMETHEE I for partial rankings,
- PROMETHEE II for complete rankings,
- GAIA plan for preference analysis.

The PROMETHEE I approach allows a partial ranking of alternatives based on the calculation of net preference index. The difference between two alternatives (a) and (b) will be favorable for alternative (a) if and only if the alternative (a) presents a higher $\emptyset^{+}(a)$ value and a lower $\emptyset^{-}(a)$ value. In the case where this difference is not clear, we must apply the complete ranking "PROMETHEE II" method to make the difference between them. In order to complete the classification, the PROMETHEE II approach is used to prioritize the alternatives as a function of the net preference index $\emptyset(a)$. The general classification allows putting in evidence a descending order, permitting the identification of the best solution. The GAIA plan "Geometrical Analysis for Interactive Aid" is used finally to show the dispersion of the criteria in relation to the decision vector and to the different alternatives.

This approach has several useful advantages to make a decision:

• The PROMETHEE I approach avoids the confusion between the criteria which may occur in AHP,

• The PROMETHEE approach requires sources of qualitative and quantitative information and can give results on the basis of their availability. This will determine the most favorable alternative for each criterion and also the criteria which are correlated positively and negatively for each alternative,

• In conclusion, the PROMETHEE approach is a very efficient tool for the sensitivity analyzes but it remains very limited to estimate the weight of the criteria prompting the idea of combining them with the AHP approach in order to make the complete model and adapt it to our need in order to be able to choose an alternative bypass road which better respects the environment.

The determination of the weight and the structuring of the problem will be made using AHP method. The PROMETHEE approach will then be used for the aggregation of the criteria and analysis of sensitivity. An overview of this combined approach is presented in the following section.

5.3 Application of Multi-criteria Hierarchical Analysis for Choosing the Best Variant of Road Layout

The determination of the criteria was carried out using GIS (Arc-Map) while the evaluation and storage of the various potential actions was done by applying the AHP method. The methodology is proposed to select the best road project in order to replace the current section vulnerable to floods. It exploits the functionalities offered by GIS for data structuring, cross-checking of information layers and spatial analysis of the different themes and includes the AHP multi-criteria hierarchical analysis approach which combines a multitude of decision criteria in a single model. It also makes a comparative evaluation of each pair of criteria and calculates their weights for the comparative assessment for each pair of alternatives next to each criterion. The task is to look the topographical, geometrical, geological and economic characteristics that define the appropriate road project for the study area. The process followed here to meet the requirements is implemented through the following major steps: problem identification and definition, representation and modeling of spatially referenced data, multi-criteria hierarchical analysis and aggregation of criteria and presentation of results.

The diagram presented in Figure 4 shows the approach which allowed us to classify the proposed road projects for the renewal of the section under consideration.

5.3.1 Construction of alternatives

The four projected roads are illustrated in Figure 5 showing the actions, which constitute the object of the decision. Spatial reference actions are referred to as alternatives.

Alternative 1: This road project covers a length of 12812.86 m. It is characterized by straight lines and arcs, i.e., 11 arcs and 4 clothoids.

Alternative 2: It is characterized by a distance of 13553.5 m. It is less hilly with small slopes.

Alternative 3: It is characterized by a length of 12215.9 m. The alignment is approximately straighter than the other two alternatives. It comprises 5 arcs and 12 straight lines.

Alternative 4: It covers a distance of 12555.7 m. It is a straight line but its topography is very uneven with hill crossing. This causes an increase in the number of civil engineering structures and consequently, an increase in investment cost and delivery time. Table 3 summarizes the criteria values for each alternative.

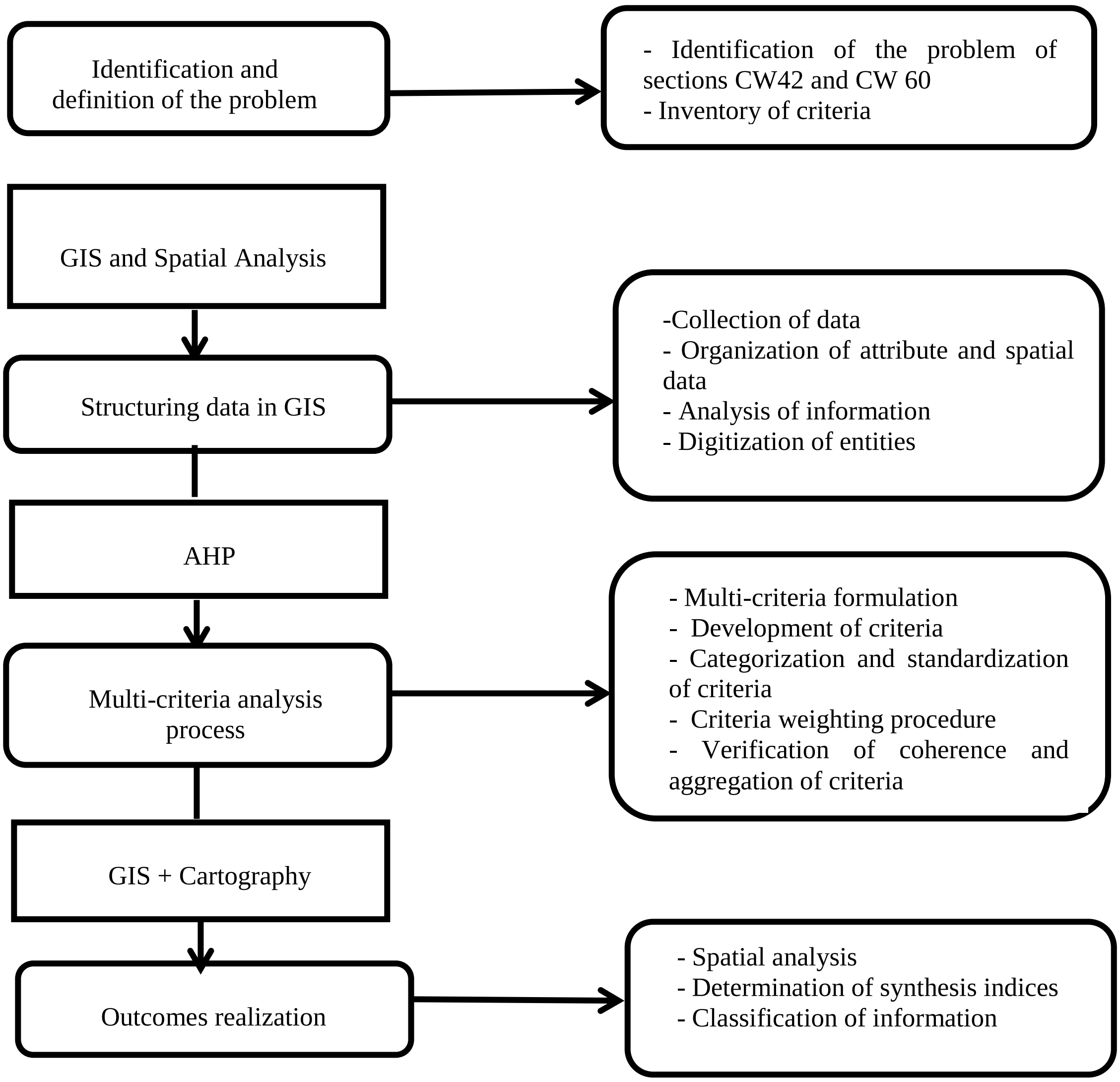

Fig. 4 - GIS and AHP integration process for spatial decision support [20]

Table 3 - Performance Matrix of road alternatives

Alternative	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Unit	m	-	-	m	u	10^6 DA	-	min	-
A1	12813	3,586	0.049	699	4	1553	62331	10,63	56580
A2	13554	2,728	0.05	725	3	972	66333	11,731	85420
A2	12216	2,264	0.005	1001	6	440282	64994	7,7733	53740
A3	12556	3,309	0	1465	3	246144	74078	7,5325	55120

(1) Length of section, (2) average overall elevation, (3) Mean sinuosity index, (4) Distance from flooded area, (5) Number of structures, (6) investment cost, (7) Geology, (8) travel time, (9) Natural terrain slope.

Fig. 5- Projection of the four road projects on a topographic map – scale: 1: 50000

5.3.2 Construction of criteria

Identification of evaluation criteria was done in collaboration with the public works managers. The given criteria in the multi-criteria hierarchical formulation are related to the quality of the achievement of the objective as the various indicators are compared and the relative importance of each for the others determined using the AHP method and a matrix report. Pair-wise comparison is therefore obtained. The pair-wise comparison within the AHP can be performed through the comparison tables shown below. The determination of the intensity of importance is made by comparing each pair of criteria and assigning them a weighting coefficient. The following nine criteria were considered:

Criterion 1: Section length

Criterion 2: Average overall elevation h/L: The sum in absolute value of the successive difference in level encountered along the route, formulated by Expression (11), and the total overall elevation. This criterion is to be minimized,

$$h_l = \sum P_i * l_i \tag{11}$$

Criterion 3: The mean sinuosity of a route is equal to the ratio of the sinuous length, LS and the total length of the route, the sinuous length LS is the cumulative length of the curves of radii in the plane less than or equal to 200 m, expressed by Expression (12). This criterion is to be minimized,

$$\delta = L_S/L \tag{12}$$

Criterion 4: Distance from the flooded zone represents a factor of safety and guarantees a durability of the projected road.

Criterion 5: The number of works of art (structures along roads), i.e., the crossing of the thalwegs increases the investment cost and the difficulty of realization.

Criterion 6: The cost of investment (in Algerian Dinars): the cost of implementation is an essential factor from the economic point of view.

Criterion 7: This criterion is related to geology, before starting a road survey, it is necessary to have prior information on the constitution of the subsoil, a geotechnical study must provide for soil survey along the axis of the structure. It is necessary to ensure the stability of the slope of cuttings. Two types of problems are encountered:

- Superficial problems: erosion and falling rocks,

- Depth problems: mass sliding in the cuttings that could affect the embankment slope, the platform and even the embankment part in the case of a mixed profile. The first ones require a geo-technical knowledge of the soft or rocky soils that will be found on the slope side after clearing. In order to foresee the soil fixing works that could prove indispensable.

Criterion 8: Travel time is the time required covering the route.

Criterion 9: The slope natural terrain, we are interested here in the stability of natural slopes or slopes where an earthwork (cuttings or embankments) is carried out and in the stability of the slopes of cuttings. The purpose of the study is to ensure the durability of the work by estimating on the one hand and the risks of instability and their percussion on the other.

Criteria 2, 3, 5, 6, 8 and 9 are to be minimized while criteria 4 and 7 are to be maximized.

After obtaining the comparison matrix, the eigen-value of each matrix and its corresponding eigenvector are determined. The eigenvector indicates the order of priority or hierarchy of the studied characteristics or activity. This result is important for the assessment of probability, since it will be used to indicate the relative importance of each operating criterion. The eigen-value is the measure that will make it possible to evaluate the coherence or the quality of the obtained solution, thus representing another advantage of this method. Subsequently, the comparison matrix is normalized so that the sum of all weights equals 1 (Table 4).

Table 4 - Comparison Matrix and Importance Weights for the Evaluation Criteria

Criterion	1	2	3	4	5	6	7	8	9	Weight
1	1	1/6	1/5	6	4	5	5	1/7	1/2	0.079
2	6	1	1/2	1/7	1/4	1/8	1/6	1/3	1/5	0.268
3	5	2	1	1/6	1/3	1/7	1/5	1/2	1/5	0.261
4	1/6	7	6	1	4	1/2	2	5	3	0.023
5	1/4	4	3	1/4	1	1/5	1/3	2	1/2	0.018
6	1/5	8	7	2	5	1	3	6	4	0.028
7	1/6	6	5	1/2	3	1/3	1	4	2	0.195
8	7	3	2	1/5	1/2	1/6	1/4	1	1/3	0.084
9	2	5	4	1/3	2	1/4	1/2	3	1	0.044
Coherence ratio	0.08 = 8% < 10 %									

(1) Length of section, (2) average overall elevation, (3) Mean sinuosity index, (4) Distance from flooded area, (5) Number of structures, (6) investment cost, (7) Geology, (8) travel time, (9) Natural terrain slope.

Identification of evaluation criteria was done in collaboration with the public works managers. The given criteria in the multi-criteria hierarchical formulation are related to the quality of the achievement of the objective as the various indicators are compared and the relative importance of each for the others determined using the AHP method and a matrix report. Pair-wise comparison is therefore obtained. The pair-wise comparison within the AHP can be performed through the comparison tables shown below. The determination of the intensity of importance is made by comparing each pair of criteria and assigning them a weighting coefficient. Table 5 below shows the matrix comparing alternatives to the criteria (length, the cumulated elevation, mean sinuosity, Flood distance, number of works, Investment).

Table 5 - Comparison matrix of alternatives by pair with respect (length, the cumulated elevation, mean sinuosity, Flood distance, number of works) criterion

Length; Inc = 0.06	**variant 1**	**variant 2**	**variant 3**	**variant 4**	**Weight**
variant 1	1	4	1/5	1/3	0.218
variant 2	1/4	1	5	1	0.639
variant 3	5	1/5	1	4	0.049
variant 4	3	1	1/4	1	0.095
Average overall elevation; Inc=0.06					
variant 1	1	1/4	1/5	2	0.305
variant 2	4	1	1/4	6	0.114
variant 3	5	4	1	8	0.049
variant 4	1/2	1/2	1/8	1	0.532
mean sinuosity index; Inc=0.06					
Trace 1	1	1	1/4	1/5	0.438
Trace 2	1	1	1/4	1/5	0.438
Trace 3	4	4	1	1/2	0.087
Trace 4	5	5	2	1	0.038
Flood distance; Inc=0.05					
Variant 1	1	1/3	1/5	1/9	0.564
Variant 2	3	1	1/3	1/9	0.282
Variant 3	5	3	9	1/4	0.115
Variant 4	9	3	4	1	0.039
Number of art works; Inc=0.06					
Variant 1	1	1/2	4	2	0.143
Variant 2	2	1	5	1	0.113
Variant 3	1/4	1/5	1	1/4	0.573
Variant 4	1/2	1/2	4	1	0.171
Investment Cost; Inc=0.07					
1	1/4	4	1/5	0.226	1
4	1	9	1/3	0.083	4
1/4	1/9	1	1/9	0.646	1/4
5	1/5	9	1	0.045	5

5.3.3 Comparison matrix of alternatives by pair with respect to Geology criterion

To establish the comparison matrix, it is first necessary to have the weights of each characteristic or activity and each geological layer once the layers of information relating the assessment criteria have been established and weighting factors assigned. It is easy to combine them to synthesize a composite decision on the optimal alignment. The most common and well-known technique of this approach is the weighted linear combination or weighted sum which fully integrates all the criteria considered into one. It consists in multiplying each factor layer by its respective weighting coefficient and then adding these results to produce an aptitude index for each variant within the range 0 to 10 identical to that of the factors and whose sum of weights is equal to 1. Once the decision layers have been evaluated, we have subsequently associated them with a weighted linear combination in order to create an aptitude index given by Equation (13) by consulting a civil engineering geology expert who collaborated to standardize values on a continuous aptitude scale ranging from 0 (the least fit) to 10 (the most fit). The Fitness value of each geological formation is shown in table 6 below.

$$V_i = \sum a_{ij} * W_j \quad \text{pour i= 1,………9} \tag{13}$$

a_{ij}: Weighting coefficients evaluating the relative importance of the criteria,

W_j: weight of each criterion, and V_i: sum indices

Table 6 - Suitability value of the geology criterion

Geological formation	Fitness value
lake limestone with plan or bismantelli and solidus	8
quartz sandstone	7
micaceous zone	4
Ostrea crassissima sandstone	7
recent alluvium	2
helvetian clays	2

So the sum indices of each route are presented below:

Variant 1= 62331.28; Variant 2 = 66333.01; Variant 3 =6 4994.25 and Variant 4 = 74077.8. The significance ratio of each of the judgment-based criteria is summarized in the comparison matrix in the following table 7:

Table 7. Comparison matrix of alternatives by pair with respect to the (geology, travel time) criterion

Geology; Inc=0.04	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**	**Weight**
Variant 1	1	1	1/2	1/5	0.349
Variant 2	1	1	1/3	1/5	0.396
Variant 3	2	3	1	1/5	0.195
Variant 4	5	5	5	1	0.060
travel time; Inc=0.05					
Variant 1	1	2	1/5	1/5	0.354
Variant 2	2	1	1/4	1/5	0.472
Variant 3	5	4	1	1/5	0.105
Variant 4	5	5	5	1	0.070

5.3.4 Comparison matrix of alternatives by pair with respect to slop natural terrain criterion

The same principle as the geology criterion using the weighted sums method is applied to assign weight by slope class. Table 8 groups the generated values, the pair comparison matrix of alternatives for natural slope terrain.

Table 8 - Weight values by slope class

Class of slopes	Weight
0-5	6
5-15	5
15-25	4
25-35	3
35-45	2
>45	1

The sum index of each route is presented below:

Variant1 = 56580; Variant 2 = 85420; Variant 3 = 53740 and Variant 4 = 55120

and the summary index of each plot is presented as follows:

Variant1=56580; Variant 2=85420; Variant 3=53740 and Variant 4=55120. The significance ratio of each of the judgment-based criteria is summarized in the comparison matrix in the following table 9:

Table 9 - Comparison matrix of alternatives by pair for the slop natural terrain criterion

	Variant 1	**Variant 2**	**Variant 3**	**Variant 4**	**Weight**
Variant 1	1	4	1/3	1/2	0.205
Variant 2	4	1	1/6	1/4	0.581
Variant 3	3	6	1	1/2	0.068
Variant 4	2	4	2	1	0.145
Inconsistency			0.05		

To expand our understanding of the issue, sensitivity analysis is performed. this kind of analysis is helpful in understanding the effect of changes in weights of criteria on the overall ranking of the alternatives. The implementation of AHP through Expert Choice provides four graphical sensitivity analysis modes: dynamic, performance, gradient, and two-dimensional analysis. The sensitivity analyses of the result are done in the current study using three modes dynamic shown in (Figure 6).

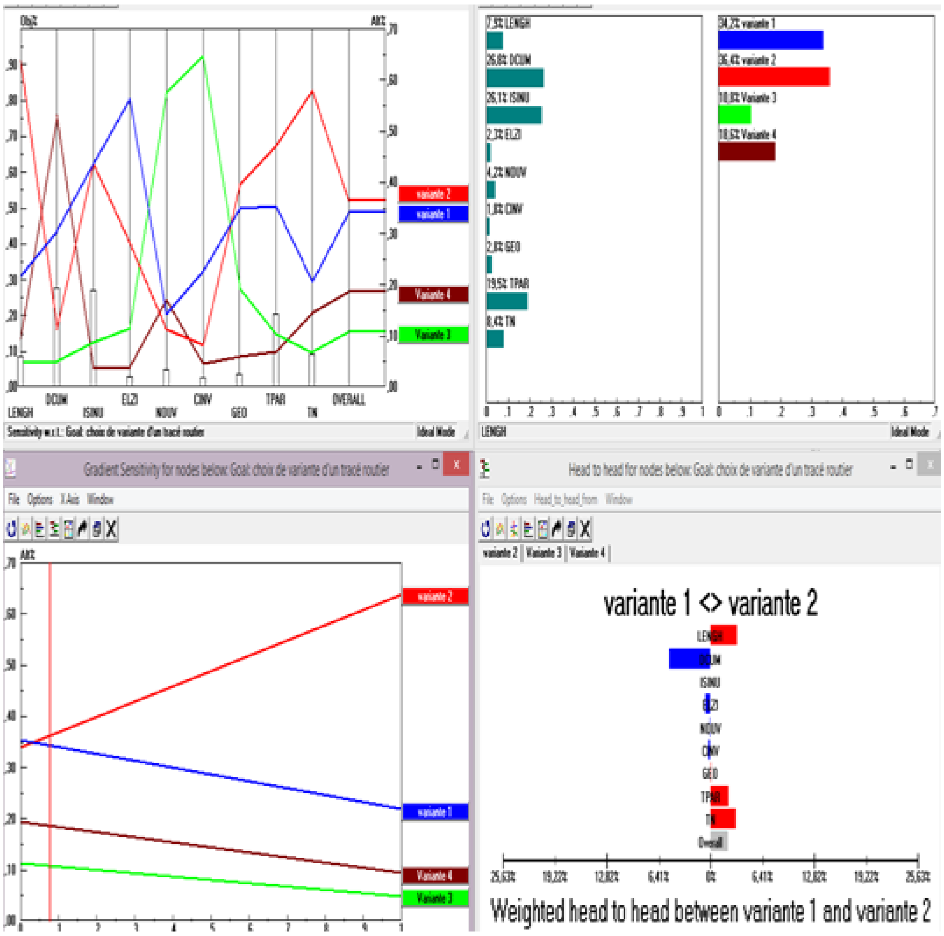

Fig. 6 - The four possible graphical sensitivity analyses in Expert Choice

The matrix performance thus built is given in (Table 10).

Table 10 - Evaluation Matrix of road variant

Criterion	Unit	Min/Max	Weight	Variant1	Variant2	Variant3	Variant4
LENGHT	m	min	10.80	12213	12556	13554	12813
DEVCUM	m	min	3.84	2.3	0	2.7	3.6
SINMOY	sn	min	2.72	0.005	0	0.05	0.049
ELOIGZI	m	man	16.14	1001	1465	725	699
NBROUV	N	min	15.01	6	1	3	4
C-INVST	M-DA	min	21.12	440282063	246	971	1553
GEOL	alphan	max	16.17	64994	74077	66333	66331
T-PARC	min	min	6.52	7.8	7.5	11.7	10.6
T-NAT	%	min	8.42	53740	55120	85420	56580

The Following step present the result of the evaluation of alternatives via Web.D-Sight software, which is used to PROMETHEE computations and analysis. The ranking and final score are presented in the (Table 11) below:

Table 11. Ranking

Rank	Alternative	Score
1	Variant 2	92.929
2	Variant 1	43.360
3	Variant 3	41.521
4	Variant 4	22.191

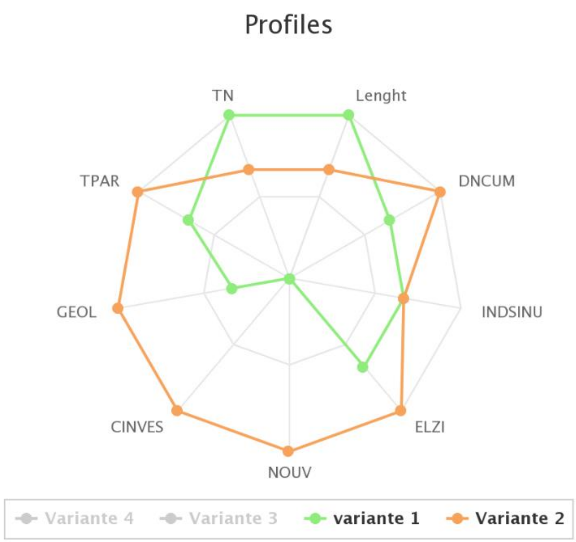

Fig. 7 - Result using SPIDER WEB CHAR

The PROMETHEE II (partial and complete ranking) analysis shows that Alternative 2 is the one that best satisfies our preference. Alternative 2 presents a score of the order of 92.929, followed by Alternative 1 with a score of the order of 43.360 while Alternatives 3 and 4 scored 41.521 and 22.191, respectively as shown in Table 12 and in Figure 7 depicting profiles from SPIDER WEB CHAR. According to GAIA analysis all our criteria are positioned in the same direction but the conflicting criteria are positioned in the opposite direction. We conclude that the number of structures, the geology, the cumulative height difference and the travel time are the criteria that express a similar preference and converge towards the direction of Alternative 2. However, the index of sinuosity and the section length are the criteria which oppose the choice of the global preference which ranks Alternative 2 in the best position. Alternative 1 was favored by criteria of travel time, sinuosity index and section length and ranked in the second position. Alternative 3 was enhanced by criteria of number of structures and geology but Alternative 4 opposed all the criteria and ranked last. The result of criteria contribution for each alternative is shown in Figure 8.

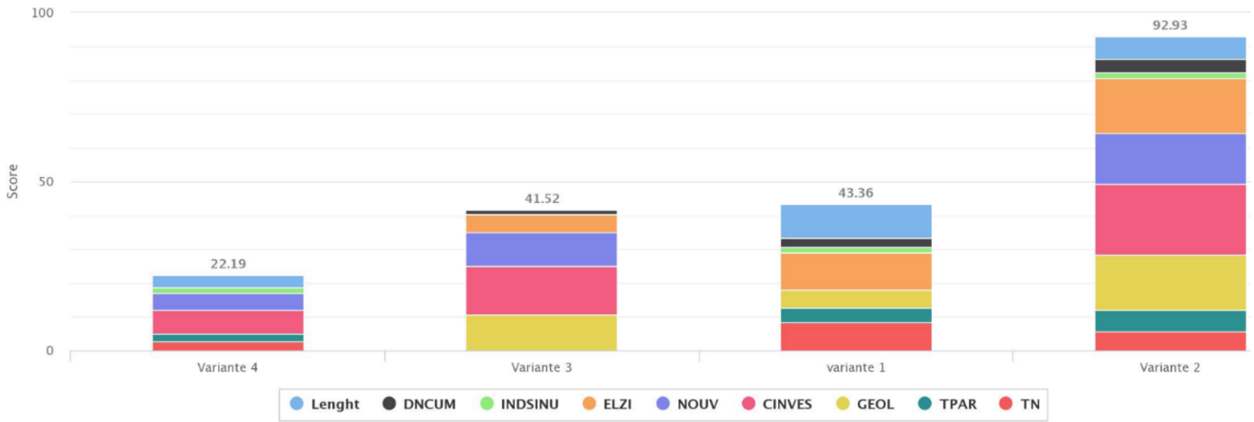

Fig. 8 - Result of Criteria contribution for each alternative

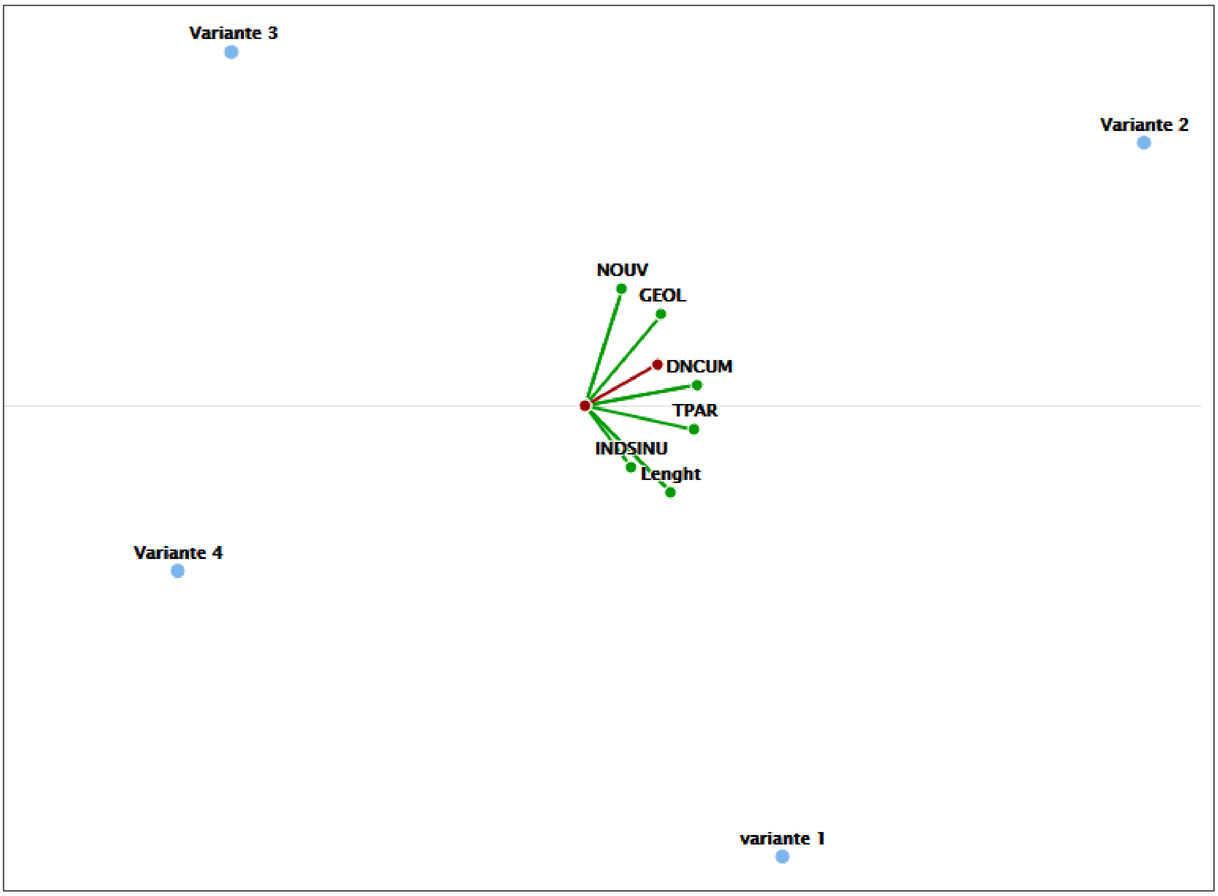

Fig. 9 - GAIA Plan showing the four studied alternatives

According to the Gaia plan (Figure 9), the most favorable alternative is Alternative 2, followed by Alternative 1 while Alternative 3 is the less advantageous among the proposed alternatives. According to AHP analysis, the fact that the Inconsistency Factor is equal to 0.08 (less than 0.10) points out that the decision criteria matrix is consistent. The

PROMETHEE method was used to find the best road project out of four alternatives (Alternative 1: 12213 m, Alternative 2: 12556 m, Alternative 3: 13554 and Alternative 4: 12813 m). From the results of both PROMETHEE and AHP methods, the best road project.

6 Results and discussions

The Multi-criteria Analysis (AHP) combined with GIS has provided valuable decision-making support for the choice of the best road project among four road alignments in order to replace a section belonging to CW42 and CW60 Wilaya ways connecting the Sidi Belattar urban area to National Road RN 90. Some parameters were to be minimized while others maximized. It may be noted that Alternative 2 and Alternative 1 were ranked first by both AHP and PROMETHEE methods and are therefore a recommended choice. They are followed by Alternative 4 and Alternative 3, respectively according to PROMETHEE method and Alternative 3 then Alternative 4 according to the AHP method. The final comparative result is summarized in Table 12. The result of the aggregation of the different criteria according to their weight enabled the classification of the four road projects. The calculation of the weights by AHP revealed that the average overall elevation is evaluated as the most important factor with 26,8% followed by : the mean sinuosity index with 6.1%, the travel time with 19.5%, the natural slope terrain with 8.4% , the section length with 7.9%, the number of structures or art works with 4.2%, the geology with 2.8% and finally the investment cost with 1.8%. The consistency index (ratio of coherence calculated in the pair-wise comparisons RC = 0.08< 0.1 or 10%) shows that the basic judgment is reasonably and strongly coherent. Starting from the basic weights resulting from pair-wise comparison, the conservation of the hierarchy in the importance of the criteria established by this approach can be noted. However, it can be noted that the most important criteria remain the investment cost and the distance from flood area. Other significant factors that follow are geology, natural slope terrain, the number of structures, travel time, mean sinuosity and average overall elevation and distance from flood area. In order to authenticate the results, the question that had to be answered was to what extent the classification obtained from the road projects was objective and realistic. The results confirm the overall agreement of the parameters and weights used. It can be noted that the multicriteria assessment in the context of spatial reference has allowed us to highlight the criteria on which priority should be given for useful valuation and rational road project studies at the preliminary design stage. The results of the weighted sum method based on the calculated weights of the nine criteria using the SAATY method and those obtained with the PROMETHEE method are presented in Table 13. It can be observed that the results obtained by the two methods are very satisfactory.

Table 12 - Ranking according to PROMETHEE and AHP Methods

Scores		Alternatives	Rank according to PROMETHEE	Rank according to AHP
PROMETHEE method	AHP method			
92.929	0.342	Alternative 1	**2**	**2**
43.360	0.364	Alternative 2	**1**	**1**
41.521	0.108	Alternative 3	**4**	**3**
22.191	0.186	Alternative 4	**3**	**4**

7 Conclusion

The choice of the best road routes is one of the main decisions of road construction companies. This study aimed at proposing an approach using the combination of GIS, AHP and PROMETHEE methods to assist companies and stakeholders in selecting their road projects in a more objective and realistic way. The proposed approach can be applied to a study of a road project located in a vulnerable area or to any other linear civil engineering project. The methodology will assist and provide support for decision makers and stakeholders in the process of selecting the best routes for road projects. The use of GIS and multi-criteria analysis in a unique framework provides a database in the context of spatial decision-making. This study can facilitate the selection of alternative (to implement road project for instance).

It helps to overcome the difficulties linked to the number of possible solutions and to a variety of built-in criteria and the possibility of the existence of several makers.

PROMETHEE and AHP used in this study offer the possibility to compare the results efficiently. The various road projects were arranged from the best to the worst case. Alternative 2 followed by Alternative 1 and Alternative 4 then finally Alternative 3 were ranked according to the PROMETHEE method. The consistency of the results reproduced by both methods increased the confidence and affirmed the effectiveness of the approach. The results obtained in this study are generally close to the conclusions made by the AHP method which ranked Alternative 2 in the first position, followed by Alternative 1 then Alternative 3 and finally Alternative 4. Once the best road alternative for the realization is given, the decision makers can select the best option. The application of this approach was very useful to structure and organize the totality of the data dedicated to this kind of problem. The results obtained by the application of the two methods are rigorously satisfactory. The exploitation of the potentialities of this study provides a great amount of information to the decision maker. Compared to other methods, AHP is an attractive method as it allows a comparison of different alternatives. As for PROMETHEE, it allows different ranks or global (group) while taking into account possible weight alternatives and an individual ranking while taking account possible weight alternatives.

Our contribution made it possible to formalize a new approach for the management of the road network as part of the choice of the best alternative of a road layout likely to replace a geo-located stretch in a zone vulnerable to flooding. This approach can be applied to issues other than road network management. It has three main features. The first is to integrate in the formulation of the model of important factors reflecting the perception of the programming of this heritage following the method developed by SAATY. We have chosen this hierarchical model with several levels. The second particularity of the approach is to use aggregation methods that allow expressing alliances between several criteria. It also presents other more specific aspects, especially during the evaluation of the preferences where we construct for each vector of alternatives the utility vector of these alternatives then sort it in descending order. Furthermore, we make a weighted sum of these new vectors by predefined coefficients. The third particularity of the approach is the integration of a GIS for the representation of geographic data, the cross-section of information layers and the extraction of relevant information to feed the method of multi-criteria analysis of decision support. In addition, the methodology adopted takes into consideration topographic, geometric, geological and economic characteristics for the classification of alternatives. To do this, three categories of indices were spatialized in GIS and weighted using the hierarchical multi-criteria method in order to obtain a ranking of the four projected road tracks that were entirely studied as part of a preliminary design. GIS associated with multi-criteria analysis offers road network management options integrating all the parameters relating to its management and development. These techniques were applied to the geo-located study area containing the section of CW42 and CW60 located in a risk area and vulnerable to flood risks linking the Sidi Belattar urban area for renewal. It also provides professionals with information on future road projects for the development of the road network in the study area in order to protect them against the risk of flooding. The developed spatial reference database is a very valuable resource for local authorities and planning agencies in defining the development needs and densification of the road network in the study area. In addition, the applied technique can easily be extended to other areas of application or to other factors depending on the availability of data, indicating flexibility and scalability.

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